KARUK AND YUROK PRESCRIBED CULTURAL FIRE REVITALIZATION IN CALIFORNIA'S KLAMATH BASIN: SOCIO-ECOLOGICAL DYNAMICS AND POLITICAL ECOLOGY OF INDIGENOUS BURNING AND RESOURCE MANAGEMENT

A DISSERTATION
SUBMITTED TO THE DEPARTMENT OF ANTHROPOLOGY
AND THE COMMITTEE ON GRADUATE STUDIES
OF STANFORD UNIVERSITY
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

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JUNE 2020

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ABSTRACT

Fire exclusion and suppression policies, associated with timber extraction and structure protection, have precipitated unprecedented wildfires and associated destruction across California and throughout the American West. Before widespread Federal and State fire exclusion and suppression policies were enacted, American Indians intentionally set prescribed burns to enhance the abundance and quality of species and habitats fundamental to their livelihood and culture. These fires are known as cultural fires, and they limited woody fuels and, in turn, mitigated wildfire spread across the landscape. In northwest California, the Karuk and Yurok Tribes are leading recent efforts to revitalize and expand the use of cultural fires, and thus, present a distinctive and timely opportunity to evaluate the socio-ecological effects of a formerly widespread land management practice that was and still remains integral to Indigenous culture and California ecology.

This dissertation uses mixed qualitative and quantitative social and ecological methods and analyses to evaluate the cultural fire resurgence in Karuk and Yurok territory. First, I examine historical and contemporary fire management as a product of colonialism and Indigenous resistance, modes of production (e.g., capitalist timber extraction and Indigenous subsistence economies), and (de)centralized governance systems. Then I present mixed method assessments of the effects of: 1) fire proxy treatments—developed by Karuk and Yurok basketweavers in the absence of cultural burning—on the production of California hazelnut (*Corylus cornuta* var. *californica*) basketry stems; 2) re-introduced cultural and prescribed burns on hazelnut basketry stem production and basketweaver harvesting and gathering decisions; and, 3) cultural fire frequency and fire exclusion on forest stand structure and overstory species composition. I conclude with an investigation of the factors that may either constrain or facilitate the expansion of cultural and prescribed burning in northern California.

Acorns from oaks (*Quercus* spp. and *Notholithocarpus densiflorus*) and baskets composed of California hazelnut stems and other animal and plant materials were essential to pre-colonial Karuk and Yurok life, and these resources depended on cultural fire to enhance their qualities and abundance. Hence, Karuk and Yurok Tribal members resisted fire exclusion policies initiated in the early 20th century by the Federal and California State governments to conserve timber stocks and to encourage commercial tree production for timber markets. Although fire exclusion and suppression reduced cultural burning, historical documents demonstrate that resistance prevented the eradication of cultural fires, and also moderated regional timber harvests. When the USDA Forest Service and the California Department of Forestry and Fire Protection

(CAL FIRE) began to allocate resources to prescriptive burning activities for fire and forest restoration in the 21st century, the Karuk and Yurok Tribes capitalized on these developments to re-introduce cultural burning through formal agreements and partnerships. Nonetheless, throughout this region, cultural burning currently remains limited in both area and frequency primarily because of insufficient funds and regulatory constraints.

Due to entrenched fire exclusion and suppression policies, Karuk and Yurok basketweavers developed innovative cultural fire substitutes, or proxies, that replicated the disturbance of cultural fire to produce suitable basketry stems (straight and unbranched stems produced from underground buds post-fire). These proxy treatments include: cutting hazelnut stems manually, directly blistering hazelnut stems using a propane torch, and igniting surface fuels piled within hazelnut shrubs to top-kill stems. The experimental application of these treatments across 27 (16 m^2) blocks resulted in the following outcomes. Compared to untreated shrubs, pile burning, propane torching, and cultural burning increased basketry stem production by 7- to 10-fold; while cutting increased production by 4-fold. These results demonstrate that these fire-proxy methods are an effective means to increase the production and the quality of basketry materials and, thus, could be integrated into forest restoration and fuel reduction projects when and where conditions for cultural burning is unfeasible.

Since 2013, the advent of annual and biannual Prescribed Fire Training Exchanges (TREX) in Karuk and Yurok territory effectively expanded cultural burning, wherein ~552 ha was burned in ~54 cultural fires from 2015–2019. Within 21 of these cultural burn sites, hazelnut shrub densities, hazelnut stem production, and stem qualities were monitored post-fire, along with a suite of environmental and social variables. Hazelnut shrubs one growing season post-burn produced a 13-fold increase in basketry stems compared with shrubs ≥ 3 growing seasons post-burn. Furthermore, areas burned at high frequencies (≥ 3 events from 1989 to 2019) had 1.86-fold greater hazelnut shrubs than areas burned < 3 times. Observations of hazelnut basketry stem gathering found that 73% of gathering trips were to sites burned at high frequency. Basketweavers who did not have access to cultural burn sites travelled 3.8-fold greater distances to reach gathering sites burned by wildfires, where gathering rates were 1.6 stems/minute/individual, compared with harvesting trips to culturally burned sites, where gathering rates were 4.9 stems/minute/individual. High frequency cultural burning thus increases gathering efficiency because such practices facilitate higher density resources in closer proximity to residences when compared with unburned areas.

A major objective of Karuk and Yurok cultural burns is to reduce Douglas fir (*Pseudotsuga menziesii*) encroachment on oak woodlands and prairies to maintain ecological heterogeneity, and to reduce surface fuel loads in order to protect homes and other built infrastructure in the event of a wildfire. My ecological surveys and remotely sensed analyses of deciduous tree cover found that high frequency burn sites facilitate the maintenance of hardwood tree overstories predominantly composed of deciduous California black oak (*Quercus kelloggii*), whereas low frequency burn sites (< 3 burns from 1989 to 2019) were dominated by Douglas fir. Surveys also found that cultural burns reduced leaf litter and small diameter dead, woody surface fuels (0 – 25 mm), reducing the potential intensity and rate of spread of an unplanned fire. The increased density of cultural keystone species documented in cultural burn areas provided evidence of positive human ecosystem engineering, and demonstrates that Karuk and Yurok cultural burning maintains desired ecological states that benefit Karuk and Yurok socio-economics and culture.

Given the benefits of cultural and prescriptive burning, fire managers affiliated with public land agencies, Tribes, and diverse nongovernmental organizations are working to expand the frequency and area of intentional fires. However, there remains a shortage of wildland fire teams and experts required to conduct environmental reviews to implement and plan these burns. Centralized governance of wildland fire teams diverts their labor from prescriptive burns to the suppression of wildfires, and statewide burn bans prevent cultural burns from occurring during ideal conditions. Furthermore, neoliberal policies are reducing funding for staffing to support the expansion of prescriptive burning. To address this chronic underfunding on public lands and the high costs of burning on privately owned properties, communities and Tribes have developed decentralized prescribed burn associations and independent, qualified prescribed fire teams. Interagency partnerships have also provided supplemental funding and personnel to support burning across multiple jurisdictions. Increased communication among regulatory bodies, particularly land management and air quality management agencies, has reduced bureaucratic constraints in permitting processes. Devolution of burning regulations, combined with the support of Tribal sovereignty in areas that have established burning norms and infrastructure, has considerable positive potential to accelerate cultural fire implementation and expansion.

By generating and assessing empirical ecological and social data, this dissertation corroborates Indigenous knowledge and burning practices by demonstrating that high frequency cultural burning supports ecological functionality as well as Indigenous culture and livelihoods. Integrating these Indigenous and 'Western' science approaches reveals that both cultural burning and Tribal land sovereignty are critical for collaborative efforts that seek to expand prescribed fire, reduce wildfire risk, and develop resilient fire-adaptive communities.

ACKNOWLEDGEMENTS

Dedicated to those who fight to maintain Indigenous culture, worldviews, livelihood, and autonomy—past, present, and future.

This project has been a long journey, and would not be possible without many individuals and communities. First and foremost, the sacrifice and support of my partner, Nischit, allowed me to dedicate the time toward this dissertation. She helped me organize my thoughts and provided invaluable feedback on all aspects of my work. Our daughter, Thejas, who was born during this project, kept me grounded and connected to a larger purpose: the inter-generational transmission of ecological and cultural knowledge.

My parents and extended family provided me with an incredible foundation that catalyzed my inquiries into Indigenous ecology and self-determination. Their commitment to liberation struggles and opposition to colonialism led them to support the Yurok in their fight to maintain autonomy over their fishery in the late 1970s. My family's stories inspired my initial trips to the region. My family and I would not be here today without the solidarity of others who resisted fascism and anti-Semitism in Europe, and I recognize the sacrifice of my ancestors, particularly those killed in the Holocaust and pogroms. The struggle continues.

The sacrifice and resistance of Indigenous and colonized people worldwide has indelibly motivated my research, and the persistent commitment of California Indian communities to fight for autonomy and the land is what inspires this work. This dissertation was written in Ohlone territories, where descendent communities continue to demand justice. The project itself materialized thanks to the ongoing resistance of Karuk, Yurok and Hupa Tribal members and descendants. I am grateful to those who welcomed me to learn about cultural burning, basketweaving, hunting, fishing, acorn gathering, language, world renewal ceremonies, kincentric ecology, and countless other aspects of their culture. I thank Jeanerette Jacobs-Johnny for all the good stories, cultural/linguistic knowledge, and laughter! Yôotva! For direct assistance of this project I am grateful for the leadership and dedication of the leaders (past and present) at the Karuk Department of Natural Resources and Wildland Fire: Lisa Hillman, Leaf Hillman, Chook Chook Hillman, Bill Tripp, Vikki Preston, Analisa Tripp, Kathy McCovey, Ben Saxon, Grant Gilkison, Kenneth "Binx" Brink, and Ron Reed. Downriver, I am grateful for the leaders at the Cultural Fire Management Council: Margo Robbins, Elizabeth Azzuz, Robert McConnell, Thomas Willson, Bertha Peters, and Skip Lowry. I also learned on the fireline from the members of the Yurok and Karuk wildland fire crews: Talbert Alvarado, Marty Lamebear, Andy Lamebear, Paul Aubrey, Blaine McKinnon, Herman Albers, David Medford, Rodney Grant, and several others. There were numerous basketweavers who generously shared their time with me (some of which were already mentioned), and taught me so much; they include: Verna Reece, Britney Souza, Maggie Peters, Anna Colegrove-Powell, Alita Redner, Dorothy Sylvia, Analia Hillman, Janet Morehead, Lillian Rentz, LaVerne Glaze, and Diane James. Other native leaders who I owe a great deal due to their support are: Robert McConnell Jr., Shaonna Chase, Elaina O'Rourke, Richard Myers, Frankie Joe Myers, Sinead Talley, Bari Talley, Dania Rose Colegrove, and Joe Hostler.

Many other folks on the river assisted me and helped this project materialize by giving me a place to stay, feeding me, sharing good conversation and providing material aid: Jim Ferrara (Yôotva), Gina Ferrara, Imil Ferrara, Eda, Sof, Heather Rickard, Vinnie, Devin, Juniper, Amanaka, Stormy, Shay, Ben Riggan, Konrad Fisher, Zack Taylor, and Lindsey Lascheck. Thanks also go to the staff at the Mid-Klamath Watershed Council and Orleans Somes Bar Fire Safe Council who also helped bring the project together: Will Harling, Nancy Bailey, Erica Terence, Eric Darragh, and Luna Latimer.

Within the academic realm, I am appreciative of all the scholarly support and mentorship I received. Frank Lake (USDA Forest Service Pacific Southwest Research Station) was an essential bridge between life on the river and the academy. Without his expertise and network this project would never have come to fruition. Thank you for your willingness to take on another mentee! Others who collaborate with the Karuk and Yurok Tribes have been wonderful colleagues: Cleo Woelfle-Erskine, Sibyl Diver, Carolyn Smith, Dan Sarna-Wojcicki, Jennifer Sowerwine, Tom Carlson, Kari Norgaard, Arielle Halpern, Jeff Kane, and Don Hankins. I would also like to thank Nels Johnson and Eric Knapp at the USDA Forest Service Pacific Southwest Research Station for statistical support, and equipment, respectively.

At Stanford, I am incredibly grateful for the opportunity to conduct an interdisciplinary study on anthropogenic fire. Profound gratitude goes to Rebecca Bliege Bird and Douglas Bird for initially taking me on as a student and connecting me to colleagues in Karuk territory, and to Lisa Curran for the incredible support once Rebecca and Doug moved on to Penn State. Special thanks to Lisa for the deep mentorship and dedication to my success. Other faculty who pushed me and exposed me to critical literature are Michael Wilcox, Bill Durham, Jamie Jones, Paulla Ebron, Jim Fox, and C. Matthew Snipp. Much appreciation also goes to other grad students who gave me such wonderful, incisive advice over the years: Sam Maull, Maddie Brown, Emily Beggs, Dean Chahim, Elspeth Ready, Eleanor Power, Neil Tangri, E'lana Jordan, Nestor Silva, Nate Acebo, Ciara Wirth, Alana Springer, Allison Kendra, Patrick Gallagher, David Stentiford, and David Gilbert. A special shout-out to my undergraduate mentee and accomplice Gabi Saiz who worked closely with me throughout his undergraduate career: your leadership and dedication is inspiring, and I appreciate all of your collaboration over the years. I received incredible resources and assistance from the Department of Anthropology, and I am appreciative of all the assistance from staff: Shelly Coughlan, Jen Kidwell, Donna Even-Kesef, Ellen Christensen, Maria Manzanares, Emily Bishop, Claudia Engel, and Evan Lyons.

Preceding my doctorate education, my students and colleagues from the East Bay Academy for Young Scientists (UC Berkeley) fostered my teaching and learning skills, and my commitment to participatory and community-based research methods. I am particularly grateful for Kevin Cuff (an unparalleled mentor and friend), and Jessica Díaz (an incredible teacher, parent, and compa).

I could not have pursued this degree at Stanford without the friends and professors I met while at Cornell: Jason Corwin, Scott Perez, Ding Kong, Christina Hilo, Maria Bruno, Bradley Cardozo, Jordan Wells, Nicholas Martinez, Akua Gyamerah, Marlene Ramos, Danielle Newsome, Tamar Sharabi, Nina Fixell, Antonia Daniels, Jennifer Quick, Ariana Vigil, Bhavna Devani, Michael Siegel, Christian Williams, Carly Fox, Leslie Jones, Keith Tidball, Jamila Simon, Marianne Krasny, Barbara Bedford, David Driskell, Kate Bronfenbrenner, and James Turner. Other financial support for my undergraduate education included the Bureau for Jewish Education, the Udall Foundation, and the Rosenberg Fund for Children.

Preceding Cornell, I cannot forget my K-12 teachers who encouraged my scholarly and intellectual pursuits from a young age: Nile Malloy, Geoff Ruth, Kathleen Large, Michelle Deiro, Cuca Holsen, Marg Costello, John Rivera, Lisa Guzman, Iyah, and Bill Scattaregia. I was also deeply influenced by the organizations I participated in as I grew up in San Francisco: Literacy for Environmental Justice, PODER, Third Eye Movement, Friends of the Urban Forest, SLUG, San Francisco Conservation Corps, Youth Leadership Institute, and Summer Search.

Other important friends, mentors, and grassroots intellectuals who influenced my political analysis, ecological knowledge and personal development are: Marilyn Buck, Jalil Muntaqim, Mutope Duguma, Laura Whitehorn, Susie Day, Linda Evans, Fred Ho, Steve Whitman, Nancy Kurshan, Jean Anderson, Ugo Pezzi, Dan and Joy Anderson, Amy Ng, Pecolia Manigo, Nancy Hernandez, Javad Jahi, Kali Akuno, Mama Ayanna, Nehanda Imara, Manuel LaFontaine, George Galvis, Jose Luis Pavon, Magalí Rabasa, Brooke Groucho, Laleh Behbehanian, Heidi Hoechst, Isaac Ontiveros, Jesse Strauss, Jess Heaney, Claudia Sofía Garriga-López, Francisco Perez, Azibuike Akaba, and Debayani Kar.

Of course, none of this would have been possible without my family and extended family: Claude, Diana, Leila, Joyce, Saralena, Vera, Henry, Bebe, Alex, Ron, Hari, Vijaya, Archit, Sanat, Karen, Jody, Ericka, Donna, Rob, and Zoe.

Lastly, I deeply appreciate my non-human relations with whom I developed stronger affinities through this project. I hope the nourishment and teachings I received from hazelnut, madrone, dogwood, tanoak, black oak, canyon live oak, Doug fir, pines, cedars, huckleberries, black caps, tan oak mushrooms, poison oak, blackberries, salmon, deer, elk, black bear, osprey, eagles, river otter, Stanshaw creek, Clear creek, Camp creek, Aikens creek, Miners creek, Salmon river, and Klamath river, were somehow reciprocated.

Studying and conducting cultural burns has been a transformative experience that has taught me about the profound interconnectivity of California Indian culture and ecology. I hope that this dissertation can contribute to broader transformations that address socio-ecological justice and decolonization in the Klamath river watershed, California, and beyond.

Stanford IRB provided human subjects approvals (#33064), and the project was approved by the Yurok Tribal Council and the Karuk Research Advisory Board. I am deeply appreciative of all of the sources of funding and aid at Stanford that included: Cynthia Geerdes and the School of Humanities and Sciences Community Engagement research grant, the Diversity Dissertation Research Opportunity, Center for Spatial and Textual Analysis Digital Humanities Fellowship, the Institute for Research in the Social Sciences Dissertation Fellowship, and the Woods Institute for the Environment Mentoring Undergraduates in Interdisciplinary Research (MUIR) program. I am especially grateful for external funding that backed this project: Financial funds instrumental in the initial development of this project were received from the United States National Science Foundation (NSF)'s Coupled Natural and Human Systems grant (DEB-1232319) to Rebecca Bliege Bird and Lisa Curran at Stanford University. For this project and ongoing collaborative programs with the Tribes, I appreciate the financial support from the United States Joint Fire Science Program (#L17AC00214) and NSF Doctoral Dissertation Improvement Grant (1657569). I also received additional support from a NSF Graduate Research Fellowship (DGE-114747). All opinion, findings, and conclusions or recommendations expressed here are those of the author and do not necessarily reflect the views of the NSF, US Joint Fire Science Program, or Tribes.

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CHAPTER 1

Introduction

Fire exclusion and suppression policies of the US Federal and California State government emerged in the first two decades of the 20th century to protect private and public timber stocks (Pyne 1982; Hudson 2011; Stephens and Sugihara 2018). As a result, the Indigenous burning practices that shaped the ecology of California were outlawed, negatively affecting California Indian culture and producing massive changes to California fire ecology (Martin and Sapsis 1992; Kimmerer and Lake 2001; Lightfoot and Parrish 2009; Mallek et al. 2013; Anderson 2018). Despite the persistence of these policies (Fischer et al. 2016; Schoennagel et al. 2017), California Indians have fought to revitalize what they call 'cultural burning' (Hunter 1988; Senos et al. 2006; Goode 2014). The objectives of cultural burns are to enhance and increase the abundance of species used for subsistence foods, material culture, and ceremony as well as to mitigate the spread of wildfires (Hunter 1988; Senos et al. 2006; Long et al. 2018b). In northwest California the Karuk and Yurok Tribes are making progress to re-introduce these burns as federal and California state fire policies are embracing prescribed, intentional burning to reduce hazardous fuels and mitigate wildfire risks (Fig. 1; Vinyeta and Lynn 2015; North et al. 2015; Stephens et al. 2016; Terrance 2016). The resurgence of these burns generated an opportunity to evaluate their socio-ecological effects on Indigenous livelihoods and culture.

I applied a community-based research approach to identify research questions that addressed the objectives of the Karuk and Yurok Tribes (Wilson 2008; Leeuw et al. 2012; Diver and Higgins 2014; Sarna-Wojcicki 2014). From my initial meetings with Tribal leaders, I learned that the revitalization of cultural burning was a central priority for the Tribes, and my documentation of the social and ecological dynamics of these burns would generate data to benefit Tribal objectives. Throughout this dissertation, I aimed to support the needs of Indigenous fire governance by applying the tools of Western science to Indigenous practices (Tallbear 2016). I also sought to connect Indigenous worldviews and ecological theory as their relational approaches share many commonalities (Kimmerer 2013a).

This dissertation uses mixed social and ecological methods to analyze the effects of fire exclusion and cultural burning in California's Klamath watershed. In Chapter Two I introduce the study region by analyzing the historical and political contexts that excluded fire in Karuk and Yurok territories as well as the dynamics that led to the revitalization of cultural burning from 2014 – 2019. Chapter Three entitled, "Effects of Understory Fire Management Treatments on

California Hazelnut, an Ecocultural Resource of the Karuk and Yurok Indians in the Pacific Northwest," was published in 2019 in *Forest Ecology & Management*, co-authored with Frank Lake (USDA Forest Service, Pacific Southwest Research Station) and Lisa Curran (Stanford University; Marks-Block et al. 2019). We analyzed the effects of experimental fire proxy treatments on the production of California hazelnut (*Corylus cornuta* var. *californica*) basketry stems. Karuk and Yurok basketweavers developed these treatments in the absence of widespread cultural burning. In Chapter Four, I examine the effects of re-introduced cultural and prescribed burns on hazelnut basketry stem production and basketweaver gathering decisions. Then in Chapter Five, I compare the forest stand structure and overstory species composition between areas that have been frequently burned from 1989 – 2019, and those areas that have only recently been culturally burned. Based on interviews and surveys with fire managers employed by Tribes, NGOs, private companies, and public land management agencies, I analyze what is facilitating and constraining the expansion of prescribed and cultural burning across northern California in Chapter Six. Collectively, these chapters integrate anthropological and ecological research approaches to craft a multi-faceted examination of cultural burning within a dynamic socio-ecological system.

CHAPTER 2

Resisting with Fire: Political Ecology of Indigenous Cultural Burning in Northwest California

INTRODUCTION

Before colonial occupation in 1849, Northwest California Indian cultures regularly applied fire to enhance the morphological traits and abundance of fire-adapted species that were critical for subsistence (Lightfoot and Parrish 2009; Anderson 2018). The spatial extent and distribution of pre-colonial burning was affected by sociopolitical systems that supported small group and individual resource access and control (Bettinger 2015) as well as extensive trail systems that were burned to maintain travel efficiency (Lake 2013). However, European colonialism, beginning with the gold rush in 1849, imposed an abrupt and major transition to capitalist resource extraction that rapidly transformed the subsistence economy and social organization in Northwest California Indian communities (Norton 1979; Huntsinger and McCaffrey 1995; Madley 2016). Fire exclusion and suppression policies enacted in the first two decades of the 20th century to support timber extraction and structure protection effectively reduced the extent and frequency of fire in California (Stephens et al. 2007; Pyne 2016; Taylor et al. 2016). As a result, the accumulation of forest understory fuels has contributed to the growth of wildfire area in each decade since 1980 (Miller et al. 2012; Westerling 2016). Recently, fire managers in California have embraced intentional, prescriptive burning to reduce wildfire severity and areal extent (Stephens et al. 2016; Stephens and Sugihara 2018). Yet, many governmental constraints still remain that inhibit widespread implementation of these policies (Chapter Six; Miller et al., 2020; Quinn-Davidson and Varner, 2012).

In Northwest California, the Karuk and Yurok Tribes currently lead efforts to restore prescriptive burning for cultural and subsistence objectives; this practice is locally referred to as 'cultural burning' (Long et al. 2018b). The Karuk and Yurok are two of the largest federally-recognized Tribes in the state of California (United States Census Bureau 2010a), and are using their newly acquired ability to self-govern (Strommer and Osborne 2014) as a means to establish structures and expertise to initiate a major transition from the dominant intractable fire suppression paradigm (Dods 2002; Donovan and Brown 2007; North et al. 2015; Ingalsbee 2017) toward a proactive prescriptive cultural burning system or cultural fire regime (Senos et al. 2006). These efforts to expand cultural burning are distinctive in that they are locally driven, in contrast with the majority of burning in the state, which is initiated by natural resource managers and their agencies (Quinn-Davidson and Varner 2012; Miller et al. 2020). This emergent alternative cultural fire regime can be attributed to the historical legacy of their resistance to fire exclusion policies by Tribal members and primarily motivated by their determination to maintain a culture and livelihood that is dependent on cultural burning (Davies and Frank 1992; Conners 1998; Norgaard 2019).

Here, I investigate how Karuk and Yurok Tribal members have organized politically to govern fire across history, and evaluate how external (colonial) political and economic dynamics affected cultural burning. I draw from the intellectual framework of Indigenous political ecology (Carroll 2015; Middleton 2015), which explores the effects of colonialism and capitalism on American Indian communities while also analyzing the effects of Indigenous resistance and governance on social and ecological change. This framework combines an analysis of resource control, distribution, and governance developed from political ecology with a focus upon the specific effects of settler colonialism in North America. My analysis is influenced by the liberation ecology of Watts & Peet (2004) as well as accounts of Indigenous resistance through cultural revitalization and resurgence (Alfred 2005; Simpson 2011, 2017; Clifford 2013; Kimmerer 2013b; Baldy 2018). In this analysis of fire-enhanced livelihoods in the Klamath watershed, I explore how Tribal members use fire to enact socio-ecological change.

This chapter first presents an analysis of how pre-colonial Indigenous governance, culture and worldviews influenced the fire regime to situate its importance in Karuk and Yurok socio-ecological dynamics by synthesizing archaeological, paleo-ecological, and ethnohistorical data. Using historical evidence, I then explore how this suite of socio-ecological interactions affected resistance to changes in fire governance from ~1905 to present. Lastly, I synthesize my observations during 18 field months in Karuk and Yurok territory (2014 – 2019) to examine the persistent constraints and the successful strategies that are catalyzing the expansion of cultural burning.

PRE-COLONIAL SOCIOECOLOGY OF FIRE

US colonialism—from the gold rush to present —de-valued and often destroyed Indigenous fire practices and knowledge. Therefore, pre-colonial fire regimes in northwest California are challenging to reconstruct and evaluate. Although many ethno-historical accounts include anthropogenic burning (Lewis 1993; Stewart 2002), these accounts provide few comprehensive details of the extent and frequency of this practice, how Indigenous social structures influenced both when and where fires were ignited, and by whom. Combined with archaeological and paleo-ecological evidence, ethnographic evidence of Indigenous social structure and livelihoods in northwest California (Goddard 1903; Kroeber 1925; Harrington 1932; Waterman and Kroeber 1934; Gould 1966; Thompson 1991; Stuart and Stephens 2006) can be incorporated to develop robust reconstructions of pre-colonial fire regimes. Several relatively recent studies (Lightfoot et al. 2013; Crawford et al. 2015; Liebmann et al. 2016; Taylor et al. 2016) have used these multiple lines of evidence effectively to infer how shifts in social systems affected pre-colonial fire regimes.

Biophysical Evidence of Cultural Fire

Northwest California fire histories generated from tree scars and sediment cores show that fires were more frequent preceding fire exclusion policies than following the implementation of these policies (Wills and Stuart 1994; Taylor and Skinner 1998; Crawford et al. 2015). Lake sediment cores provide longer fire chronologies than dendrochronologies, and base their inferences on charcoal accumulation rates and pollen percentages from various fire-sensitive plants (Whitlock and Larsen 2002). However, these chronologies are coarsely grained because charcoal and pollen can travel large distances and accumulate at variable rates based on stochastic environmental factors (Whitlock et al. 2004). Marlon et al. (2012) conducted fire history analyses throughout the American West and argued that climate has a greater influence over fire frequency and extent than humans preceding the industrial revolution. However, analyses of fire histories within the Pacific Northwest found that charcoal accumulations and pollen depositions of fire-adapted species occur at greater rates than would be expected if climate were the dominant driver of fire regimes (Walsh et al. 2018). A recent analysis of a sediment core from a low elevation lake (Fish Lake, 41°14′N, 123°42′W, elevation: 541 m) in Karuk and Yurok territory attributed increases in charcoal and oak pollen during cooler and wetter periods (e.g., Little Ice Age, 550-250 cal. yr. BP) to cultural burning (Crawford et al. 2015). These studies suggest that analyses at relatively small spatial scales can capture anthropogenic fire dynamics, especially when paired with archaeological data (Power et al. 2018).

Compared with sediment cores, dendrochronologies are spatially fine-grained, but tree survivorships span ~200 - 500 years and their remains decompose over time. In addition, depending on fire severity, trees may not be scarred by low-intensity fires that are the central characteristic of cultural fire regimes (Johnson and Gutsell 1994; Baker and Ehle 2001; Lentile et al. 2005). Recent models have also suggested that fire return intervals derived from standard fire scar sampling methods (e.g., which target visibly scarred trees and eliminate or filter scars that do not occur in multiple samples) have largely under-represented high frequency, small patch

Indigenous burning (Roos et al. 2019). Taking into consideration these methodological constraints, pre-colonial (< 1849 CE) median fire return intervals reported from the Klamath mountains (640 m - 1600 m a.s.l.) range from 11.5 to 16.5 years (Wills and Stuart 1994; Taylor and Skinner 1998, 2003). Moreover, at a relatively lower elevation site (541 m) within Karuk and Yurok territory, USDA Forest Service ecologists documented an 8.5 year median fire return interval (F. Lake, pers. com., 2019). These findings provide evidence that Karuk and Yurok cultural burning increased fire frequency in locations within ~3 km of their low elevation settlements compared with remote areas at higher elevation (Busam 2006).

Ethnographic Evidence of Cultural Fire

Documentation of the pre-colonial livelihoods of Karuk and Yurok Indians in early ethnographies was influenced by the memory reconstruction methods and political orientations of early salvage anthropologists, who asked informants to recount the social and cultural structures that pre-dated colonialism to preserve past practices (Buckley 1989; Lightfoot 2005). Recent collaborative archaeology with the Tolowa Dee-ni' nation generated significant data required to reconstruct past subsistence and social organization in the region (Tushingham 2009; Tushingham and Bettinger 2013). In particular, the importance of acorns in subsistence (Basgall 1987) led to the emergence of family controlled storage and a largely sedentary lifestyle (Tushingham and Bettinger 2013). The individual and familial ownership of fire-enhanced resource tracts, such as oak stands for acorns, produced a diverse and fine-grained patch mosaic of fire histories throughout Karuk and Yurok territory (Lightfoot and Parrish 2009).

Ethnographic information from Northwest California collected in the early 20th century and California Indian writings from this era contain detailed descriptions of burning to maintain a broad spectrum of plant and wildlife species for subsistence, ceremony, and material culture (Goddard 1903; Jack 1916; Harrington 1932; Kroeber and Gifford 1949; Schenck and Gifford 1952; Bright 1957; Gould 1975; Thompson 1991; Lewis 1993; Stewart 2002; Anderson 2005). These sources show that the frequency of cultural burning depended either on the habitat or the species present (that were deliberately manipulated by Indigenous peoples). Areas for seeding tobacco (*Nicotiana quadrivalvis*) were burned annually, while shrubs such as huckleberry (*Vaccinium ovatum*) and hazelnut (*Corylus cornuta* var. *californica*) were burned at ~five year intervals to improve fruit and nut production (Harrington 1932; Warburton and Endert 1966; Pullen 1996; LaLande and Pullen 1999). Tracts of beargrass (*Xerophyllum tenax*) and hazelnut were burned as frequently as every three years in the summer and fall to produce quality leaves and stems for basketry (O'Neale 1932; Thompson 1991). While the understories of oak trees (particularly tanoak; *Notholithocarpus densiflorus*) were burned annually at low intensities to improve acorn gathering efficiency and to reduce acorn pest infestation (Jack 1916; Harrington 1932; Schenck and Gifford 1952; Thompson 1991).

Prairies were burned every 1 – 3 years in the summer and fall to maintain grasses and ruderals gathered for seeds, lilies and other geophytes for 'Indian potatoes', and forage for deer and elk (Jack 1916; Thompson 1991; Huntsinger and McCaffrey 1995; Stewart 2002; Anderson 2005). Care was taken to maintain forest and prairie boundaries by initially burning on prairie edges, and extinguishing fires that entered the forest using back burns—or small fires to reduce fuel ahead of a larger fire's flaming front (Stewart 2002: 277). These prairie burns typically became possible when the first fall rains occurred or after the first frost, when forest understories were moist but grasslands had dried (Riley-Thron 2001: 174; Stewart 2002). The encroachment on prairies by shrubs and trees with fire exclusion provides evidence that these prairies were maintained through anthropogenic burning (Sugihara and Reed 1987; Skinner 1995; Weiser and Lepofsky 2009).

Burning was also an integral component of ceremonial practice in Karuk and Yurok territory (Kroeber and Gifford 1949). As a part of the ritual and ceremonial construction of the Kepel fish weir in Yurok territory, which typically occurred in July (Swezey and Heizer 1977), grasslands on either side of the river were annually burned by those constructing the dam. Ethnographic accounts suggest that burning in this context sent a message to others that the dam was complete (Waterman and Kroeber 1938). Marty Lamebear, who is a Yurok fire expert, explained that the smoke was also an important signal to the fish that it was time to move upriver, in part, by cooling the river water (M. Lamebear, pers. com., 2018). A recent study (David et al. 2018) documents that wildfire smoke does reduce river temperatures in the region thereby generating benefits for aquatic life.

In Karuk territory, collective burning of nearby mountainsides was an important component of their annual ceremonies (Kroeber and Gifford 1949; Lang 1994; Buckley 2002; Field 2008). Mary Ike, one of Gifford's sources, stated in reference to the ceremony that, "the mountain is an immortal woman, whose 'hair' has to be singed so there will not be many widows and widowers in the world…Now that the Indians no longer burn fires on Mt. Offield and no longer perform the Deerskin Dance, food is scarce and they are dying off" (Kroeber and Gifford 1949: 21). In her statement, Mary Ike describes how Karuk spiritual practice is connected to and affects the material constraints of life (i.e., food). Collective burning at these ceremonies also may have had an epiphenomenal effect of reducing the time and labor costs of burning larger areas for wildfire protection and subsistence enhancement. Hence, many individuals and families benefitting from this collective practice. The ethnographic record implies that gathering and hunting on Mt. Offield was open to many, and not owned by specific individuals and households, as long as certain restrictions were upheld (Kroeber and Gifford 1949: 21). Additionally, a recent memoir by a Karuk medicine woman states that the ceremonial town at the base of Mt. Offield (Ka'tim'îin) provided sanctuary to individuals who were banished from other areas (McCovey and Salter 2009). These statements suggest that usufruct rights to resources on this sacred mountain, and others, may have been less circumscribed than other areas owned by specific families.

In Karuk and Yurok territories, burning occurred both collectively and at the familial level, however, the evidence indicates that familial burning of resource tracts was dominant. Hence, most burning decisions were decentralized and produced relatively small fire areas (or fine-grained mosaics) of different fire histories and habitats. Because all Karuk and Yurok families relied upon fire-enhanced foods and materials, these mosaics were undoubtedly widespread. Karuk and Yurok prescriptive burns effectively reduced surface fuels, allowing for easier travel and limiting the spread of both anthropogenic and lightning ignited fires (Collins et al. 2009; McKenzie et al. 2011; Lake 2013; Parks et al. 2015). However, with the advent of the colonial extractive economy and genocide, Indigenous fire regimes were radically altered.

COLONIAL FIRE POLICY AND INDIGENOUS RESISTANCE

The Gold Rush and Initial Settlement (1849 – 1900)

Colonialism in Northwest California was motivated by the extraction of raw materials for global markets and precipitated a genocide of Northwest California Indians (Madley 2016). Settlers initially sought to appropriate gold within un-ceded California Indian territories while California Indians resisted these incursions (Norton 1979). Ultimately, settlers were able to subjugate and dispossess native communities because they were backed by state resources including the military (Norton 1979; Madley 2016).

Despite efforts to eliminate California Indians from their lands, Tribal families and villages fought to remain in their homelands in the rugged Trinity and Klamath River valleys (Fig. 1). Physical and armed combat to protect land and livelihood was common between 1850 and 1870 (Nelson 1978; Raphael and House 2007). A series of treaties between California Indians and the US Federal government in 1851 that would have given natives title to certain lands, were never ratified by the US Congress because of intensive lobbying by California settlers (Norton 1979; Rawls 1986).

The 1849 California gold rush created high demand for timber and agriculture to support the explosive growth of Western cities (Clar 1959; Laudenslayer and Darr 1990). The timber industry initially focused on the extraction of high quality Coast Redwood (*Sequoia sempervirens*) timber growing in the coastal mountains of Wiyot, Tolowa, and Yurok Indian territories (Ayres 1958; Raphael and House 2007). The settlers' dependence on domesticated livestock and agriculture directly conflicted with the Indigenous subsistence system that relied upon non-agricultural foods and materials. Thus, settlers also appropriated grasslands and prairies for livestock that had been maintained through regular Indigenous burning. To access these forests and grasslands, settlers murdered Indigenous people who killed livestock for food, and enslaved many Indian children to support their settlements (Nelson 1978; Norton 1979; Trafzer and Hyer 1999). Other Northwest California Indians were forced onto reservations and rancherias and the majority of their territories were expropriated by settler capitalists (Norton 1979; Huntsinger and Diekmann 2010). Because of the isolation of Yurok territory along the Klamath River, a reservation was created by executive order in 1855, and expanded to the confluence of the Trinity River in 1891 (Huntsinger and Diekmann 2010). The nearby Hoopa Valley reservation was created after many hard fought battles against settlers, the military, and militias (Nelson 1978). However, a reservation was never formally established in Karuk territory.

Under the auspices of the Dawes Act (1887), the federal government privatized and allotted properties on the Yurok reservation to individual Yurok Indians, which facilitated manipulative and fraudulent land purchases by settlers (Huntsinger and Diekmann 2010). Indian land allotment eventually led to additional land appropriations by timber companies on reservation lands especially in areas with commercial stocks of redwood timber (Huntsinger and Diekmann 2010).

The settler-colonial wars and the imposed socio-economic system were rationalized through religious and philosophical beliefs known as 'manifest destiny' (Stephanson 1996) and in dialectical opposition to California Indian livelihoods, spirituality, and worldviews (Merchant 1983; Scott 1998; Deloria 2003; Johnson and Murton 2007). Karuk leader Leaf Hillman writes that:

> Karuk beliefs – as exemplified in the world renewal ceremonies and creation myths, connect people from childhood to an awareness of relationship and responsibility…This relationship to other creatures has quite a different emphasis from that of western religions, which focus almost entirely on a creator which is a projection of human power, one which ignores the spiritual link and responsibility to the earth (Hillman and Salter 1997: 24).

Karuk and Yurok philosophies do not separate spiritual practices from subsistence practices, nor humans from other species and the earth (Hillman and Salter 1997; Buckley 2002). In contrast, colonial-capitalism abstracts and alienates human relations with the earth, and is based upon notions of human, male, and European cultural superiority (Marx 1967; Robinson 2000; Johnson and Murton 2007; Mies 2014; Moore 2015). The profound kinship relations between California Indians and the land constitute the foundation of their political resistance in this colonial era. Given that fire is at the core of Karuk and Yurok subsistence and spiritual relationships (Harrington 1932; Kroeber and Gifford 1949; Thompson 1991; Hillman and Salter 1997) the struggles against fire exclusion policies comprise a central component of this continuum of resistance (Norgaard 2019). What follows here is a synthesis of colonial fire and timber policy history in the Klamath watershed of California, and Indigenous efforts to oppose these policies to maintain political and cultural autonomy.

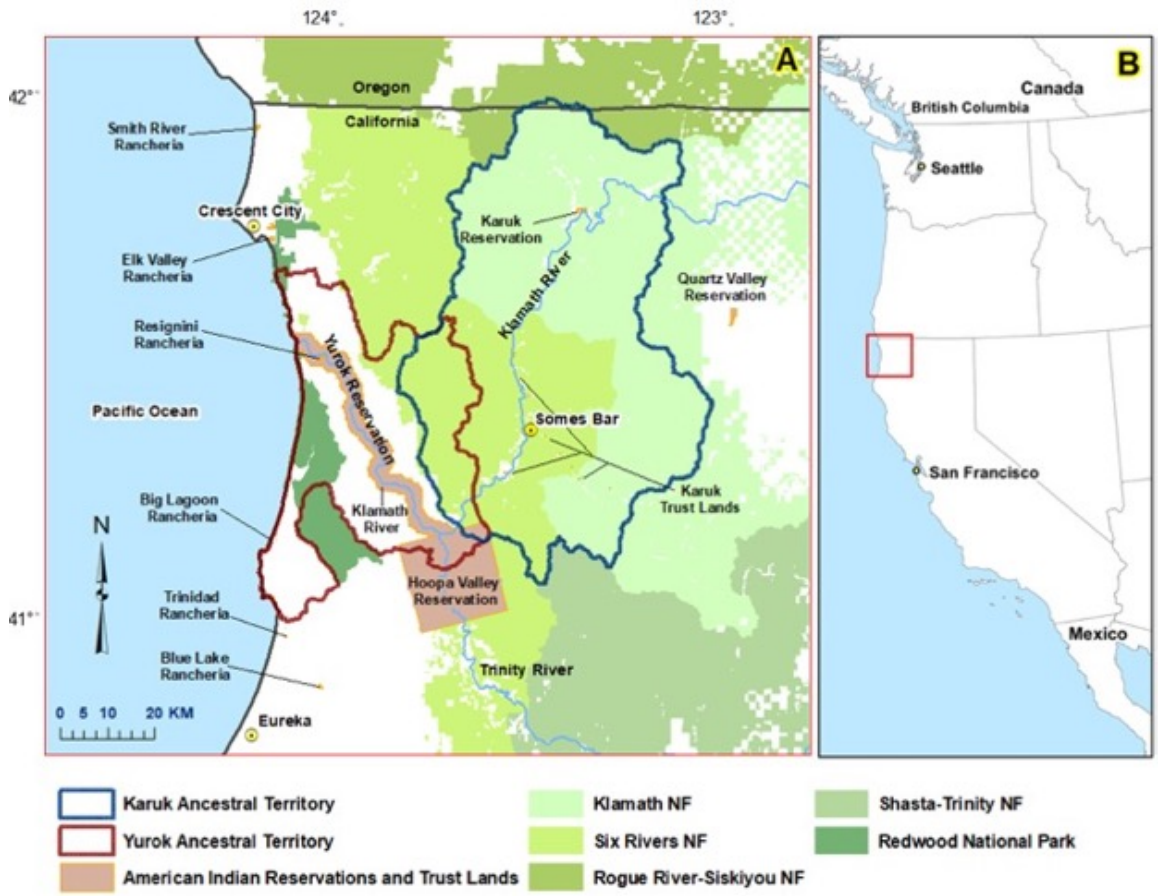

Figure 1. (A) Study Region with Federal Jurisdictional Boundaries and Karuk and Yurok Territories Ancestral territory boundaries, provided by the Karuk and Yurok Tribes, represent reconstructions, but currently are not fixed or rigid boundaries. Ancestral lands of other Northwest California Tribes (e.g., Tolowa, Wiyot, Hupa, Shasta) are not included here, but note that their ancestral lands may partially overlap with the boundaries rendered here (Baumhoff, 1963). **(B) Western Region of the United States of America.** The study region is depicted by the red box.

The Forest Service and Fire Exclusion 1905 – 1950

Through a 1905 presidential proclamation, President Theodore Roosevelt ceded the Klamath Forest Reserve, now known as the Klamath and Six Rivers National Forests (Davies and Frank 1992; Fig. 1). Karuk families' lands were particularly compromised by the creation of the Klamath Forest Reserve, as Karuk land titles initially were unrecognized. In 1910, the US Congress passed a bill that authorized land allotments (< 65 hectares) to Indians living in forest reserves as in the Klamath (Miller 2017). However, only 32 applications for 186 hectares were allotted to Karuk 'household heads' as allotted lands were required to be agricultural, and few such areas existed in Karuk territory. Furthermore, the Office of Indian Affairs (now Bureau of

Indian Affairs) provided extremely limited staffing to process these applications (Miller 2017). In 1947, over 81,000 ha of Klamath National Forest were transferred to the newly created Six Rivers National Forest that extended south and west into the territories of the Yurok, Hupa, and other Tribes, and North and West into Tolowa Tribal territory (Conners 1998, Fig. 1).

With the establishment of National Forests, fire use became a major land management conflict between the state and local residents (Hudson 2011). The USDA Forest Service and the State of California Board of Forestry strictly opposed intentional burning because they believed such fires threatened their timber stocks and timber regeneration (Show and Kotok 1924; Clar 1959; Pyne 1982). These agencies opposed the appropriation of Indigenous burning practices by timber companies and ranchers, and further employed racist tropes of Indians to galvanize support for their fire exclusion policies (Graves 1920; Leopold 1920).

In the first four decades of the Klamath National Forest, the USDA Forest Service generated management funds by leasing land to ranchers for grazing their cattle (Davies and Frank 1992). The criminalization of burning on the one hand, and the encouragement of cattle grazing on the other, reflected an ignorance harbored by forest managers especially as these grasslands required repeated burning to be sustained. In the 1940s, ranching became so pervasive and intensified that cattle began denuding grasslands and outcompeting deer populations for browse (Davies and Frank 1992). As a result of the destruction of Indigenous property regimes and the governmental criminalization of their subsistence practices, California Indians who lived within or near the Klamath National Forest were forced into the market and wage economy of the United States. That economy was dominated by cash crops (e.g., cattle and timber) and government-funded employment associated with fire suppression (Davies and Frank 1992; McCovey and Salter 2009; Norgaard 2019).

Until the 1940s, there was not a substantial infrastructure to support a timber industry in the Klamath National Forest; Nonetheless, the Forest Service hired individuals to monitor fire from lookouts, fight existing fires, and to fine incendiaries to protect future timber markets (Davies and Frank 1992). Because few suitable wage opportunities existed in the region, California Indians along with white settlers surreptitiously set fires to receive temporary jobs suppressing fires (Davies and Frank 1992; Conners 1998). Forest Service staff accounts of fire suppression between 1905 and 1960 also attribute many incendiary burns to Karuk and Yurok Indians who continued to burn to improve grazing and wildlife conditions as well as to promote basketry materials (Davies and Frank 1992; Conners 1998; Busam 2006). These ‘illegal’ fires set by Karuk and Yurok Indians reportedly frustrated Forest Service staff for decades. As the Orleans District Ranger in 1918 wrote: “The only sure way [to control the fire problem] is to kill off [the renegade Indians] every time you catch one sneaking around in the brush like a coyote. Take a shot at him." (Davies and Frank, 1992: 90) Such demeaning and antagonistic attitudes toward Karuk and Yurok peoples remained prevalent among Forest Service staff throughout this period. In 1949, a Six Rivers National Forest inspection report stated that Indians are "uncivilized…[and] more or less confirmed in their thinking that the land should be theirs and that incendiarism is one way of retaliation towards the white man for various controls, disciplines and laws" (Conners, 1998: 110). These historical documents confirm that Karuk and Yurok Indians actively sought to maintain their cultural burning practices and used fire to subvert state objectives of fire exclusion for timber production.

Not all Forest Service staff were in direct opposition to the Karuk and Yurok uses of fire. In a Six Rivers National Forest cultural resource interview in 1983, a former Klamath National Forest supervisor and Six Rivers National Forest staff member from the 1920s – 1960s stated:

> I got word that they were running out of, or they were having trouble finding, hazel sprouts to make their baskets so I just dropped the word, if they knew there was a patch of hazel brush that needed burning off to get sprouts, I'd help them, and we did…That's all it took to breakdown that adversary relationship, cooperation (Six Rivers National Forest Heritage Program, 1983: Inerview 346).

Despite directives from USDA Forest Service Chiefs and other administrators, some USDA Forest Service staff or forest supervisors did not strictly adhere to fire exclusion policies. Thus, the implementation of policies was far from monolithic and the political orientation of Forest Service staff could facilitate some Indigenous objectives while simultaneously subverting others. Karuk and Yurok communities thus were able to educate or convince some governmental representatives that some burning practices were either legitimate or did not threaten the timber objectives of the USDA Forest Service. Because Karuk and Yurok territories are so isolated, many of the early USDA Forest Service staff either were descended from Karuk and Yurok Indians or married to Karuk and Yurok Indians, and these familial relationships likely attenuated potential antagonisms and helped to overcome cultural divides (Hotelling 1978; Davies and Frank 1992; Conners 1998). Moreover, these social and kinship ties often catalyzed efforts to increase burning for Indigenous resources from the 1970s through the present. However, these familial relationships were relatively ineffective in mitigating the major ecological shifts precipitated by industrial-scale timber extraction.

Timber Extraction and Resistance 1950 - 1995

Once old-growth redwood timber stocks were exhausted in coastal northwest California, demand increased for inland Douglas fir and Ponderosa pine forests, particularly after World War II (Clar 1969; Schrepfer 1983; Huntsinger and McCaffrey 1995). Initially, a lack of an extensive road network hampered logging in the Six Rivers and Klamath National Forests (Hopkins 1964; Strothmann and Roy 1984). Then the construction of roads in the 1950s and 1960s led to an explosive increase in logging and clear-cutting from 1960 – 1980 (USDA Forest Service PSW Region, 1995; Fig. 2) that further exacerbated sedimentation and erosion rates caused by gold mining and further compromised aquatic habitats and fisheries (Grobey 1980; McEvoy 1986). The 1978 creation of Redwood National Park on privately owned (formerly Yurok) timberlands resulted from a brokered compromise among the conservation movement and the federal and state governments that permitted increased timber removal in Six Rivers National Forest to support the local timber-dependent economy (USDA Forest Service PSW Region 1979; Schrepfer 1983). A Forest Service study found that in order to prevent declining timber yields, they needed to increase clear cutting, harvest more old-growth timber, and expand timber plantations on areas where hardwoods (e.g., tanoak, Pacific madrone, and California black oak) dominated (USDA Forest Service PSW Region 1979).

The Forest Service established timber plantations after initial old-growth timber extraction by burning residual timber slash and planting trees (Strothmann and Roy 1984). To maximize productivity, the Forest Service sought to eliminate competition from non-commercial tree species and wildlife, extensively using herbicides and pesticides while also investing resources into studying the efficacy of several chemical applications (Schubert 1950; Strothmann and Roy 1984; Harrington and Tappeiner 2009).

Plantation expansion coupled with herbicide and pesticide applications prompted resistance from California Indian communities who experienced negative health outcomes from chemical drift and residues on basketry plants and forest foods (Ortiz 1993; Huntsinger and McCaffrey 1995; Segawa et al. 1997; Mathewson 2007; Norgaard 2007; McCovey and Salter 2009). In 1980, "40% of forestry positions in Orleans have gone unfilled…[because] employees' lives are filled with intimidation and harassment…[due to] people who are against the Forest Service's use of herbicides" (Conners 1998: 190). While organizing against spraying led to temporary injunctions that prevented the spraying of certain chemicals, to date the use of herbicides by the Forest Service and private timber companies remains a source of conflicts in the region (O'Brien 1990; LeBeau 1998; Norgaard 2007).

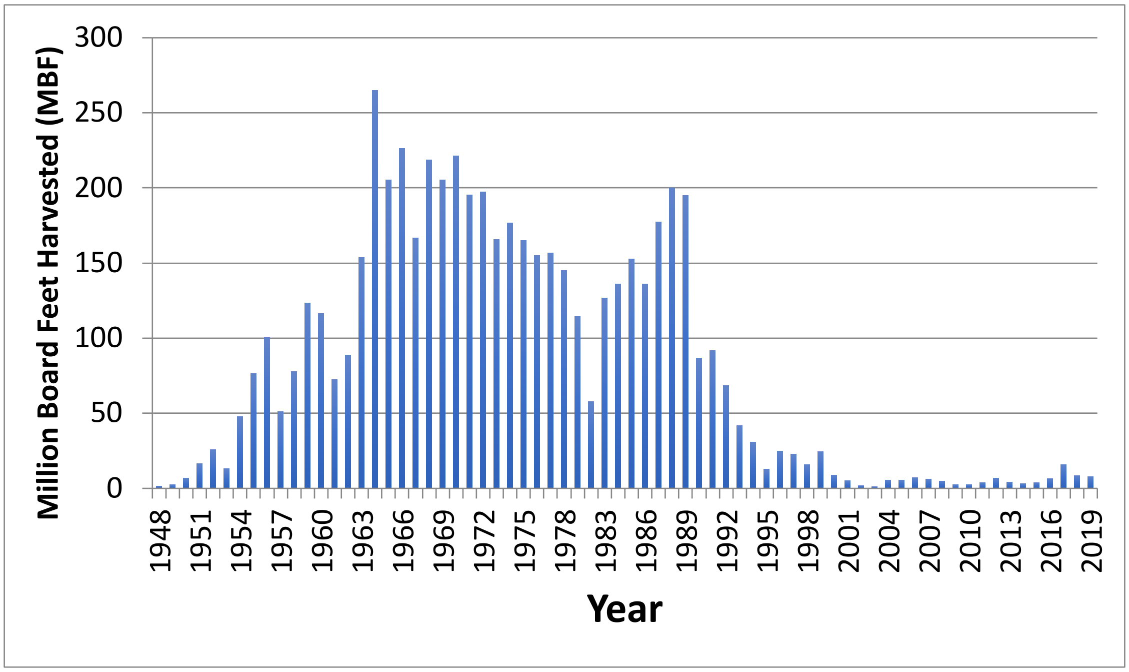

Figure 2. Annual Timber Harvest (Million Board Feet) from Six Rivers National Forest. Data compiled from USDA Forest Service reports (e.g., USDA Forest Service PSW Region, 1995, 1979).

Resisting road construction was also a prominent arena for Indigenous resistance to the Forest Service. In the road building boom of the 1960s, the Gasquet-Orleans (GO) road and numerous other logging roads were proposed for construction in a sacred area in the Siskiyou mountains where Karuk, Yurok, and Tolowa Tribal members and ceremonial practitioners conducted ceremonial practices (Buckley 2002; Bowers and Carpenter 2011; Baldy 2013). These roads were proposed primarily to facilitate logging. A coalition of environmental and Indigenous groups sued the Forest Service over many decades, arguing that their plans violated the National Environmental Policy Act of 1969, the National Forest Management Act of 1976, and the American Indian Religious Freedom Act (AIRFA) of 1978 (Falk 1989). Initial archaeological reports made by Forest Service staff justified logging based on interpretations of reports produced by UC Berkeley anthropologist Alfred Kroeber, who erroneously found that the Yurok cultural pattern of using the high country for their ceremonial practices was no longer extant in the early 1900s (Buckley 2002).

After decades of litigation, the federal government argued that logging would provide a greater public and national good (i.e., jobs and capital) than respecting Indigenous religious freedom, and the Supreme Court then overturned the decisions of lower courts, and thus, allowed the construction of roads in the Six Rivers National Forest (Falk 1989; Buckley 2002; Bowers and Carpenter 2011). However, the roads in question ultimately were not built as the US Congress declared this region a wilderness area in 1990, again without recognizing Indigenous sovereignty or religious claims (Baldy 2013).

While the battle over the GO road galvanized significant support and connected issues of Indigenous sovereignty to environmental destruction, the Forest Service continued to sell timber to logging companies throughout the Klamath mountains. In the mid-1980s, Karuk resistance to another timber sale on Offield Mountain eventually forced the Forest Service to retract the sale and recognize the 4,836 ha region as a Cultural Management Area of the Karuk Tribe (Diver 2016).

Within the Pacific Northwest region, similar actions were undertaken by the broader environmental movement to resist large-scale timber extraction (Durbin 1996). In 1994, the Clinton administration released a Northwest Forest Plan (NWFP) to guide public land agencies to conserve habitat for the Spotted Owl and anadromous fish, maintain jobs for loggers, and increase consultation with Tribes (Thomas et al. 2006; Vinyeta and Lynn 2015). The mainstream media and politicians simplified the northwest timber struggle as one between saving timber jobs or protecting owls (Durbin 1996). However, timber conglomerates had been overharvesting for decades, were competing within a highly competitive globalized market, and had increased mechanization to cut costs. All of these factors contributed to substantial declines in employment in this regional timber sector (Hirt 1996; Prudham 1998; Helvoigt and Adams 2009; Bliss et al. 2010).

The NWFP enforced reductions in the annual allowable timber harvest and required new forest plans for national forests that identified late-successional reserves with additional protections for endangered species (Thomas et al. 2006). These legal changes invited increased scrutiny of timber harvesting plans by environmental organizations, and, as a result, National Forests in Karuk and Yurok territories reduced their timber harvesting by ≥ 50% from 1994 - present (Charnley et al., 2018; Fig. 2). Although the loss of timber-related jobs depressed local economies, ecological restoration and fire management programs expanded within the USDA Forest Service as well as within Tribal government structures and created new job opportunities for Karuk and Yurok Tribal members (Charnley et al. 2008, 2018; Hibbard and Lurie 2013).

Resurgence of Cultural Fire

In the 1980s and 1990s, Tribal members capitalized on the broadcast burning of timber slash post-logging and the mowing of vegetation along roads to access their fire-enhanced resources (Heffner 1984; Hunter 1988; Ortiz 1998; Smith 2016). In Karuk territory, social and kinship ties between Forest Service personnel and Tribal members allowed basketweavers to influence site selection of broadcast burns for basketry materials (Hunter 1988; Ortiz 1998; Smith 2016). Some Forest Service staff recognized that conducting these cultural burns helped to improve relations with Tribal members (Hunter 1988) that had remained antagonistic. In the late 1990s, small-scale burning for basketry materials was catalyzed by relationships initiated through a Forest Service sponsored annual basketweaver gathering called 'Follow the Smoke' (Ortiz 1998). Later, many of these cultural burns continued through the 'Roots and Shoots' program of the Six Rivers National Forest, Orleans and Ukonom Ranger Districts (Colegrove 2014).

Persistent efforts by Tribes to assert their sovereignty using changes in environmental and Indian law has iteratively made planning and forest management processes increasingly amenable to their objectives. However, plans to integrate Karuk Tribal objectives into forest planning as 'co-management' in the 1990s to early 2000s suffered because new Forest Service personnel disrespected previous agreements (Diver 2016). Tribal members note that support for burning in the Forest Service is cyclical largely because of personnel fluctuations. When supportive staff leave the region, basketweavers must re-invest in relationships with new staff (Smith 2016). On the Yurok reservation, where the California Department of Forestry and Fire Protection (CAL FIRE) regulates burning, staff re-assignments have also disrupted positive agency-community relationships (S. Nix, pers. com., 2017).

Regional fuel reduction projects developed from the Healthy Forests and Restoration Act of 2003 (Davis 2004; Sun 2006) involved community input and partnerships with the Forest Service, but ultimately were viewed as problematic by the Tribe and local environmental organizations (Scott-Goforth 2013). In 2010, the Six Rivers National Forest mis-managed the Orleans Community Fuels Reduction project co-developed with the Karuk Tribe in the town of Orleans by allowing excessive and destructive timber removal practices along Karuk spiritual trails. These events prompted a lawsuit that was eventually settled, but amplified long-held distrust toward the Forest Service (Scott-Goforth 2013; Tripp 2019). The Orleans Community Fuels Reduction project was an initial attempt at co-management and community forestry tied to neoliberal legislation: this project sought to limit environmental regulations and use timber thinning and extraction misrepresented as a form of wildfire risk reduction (McCarthy 2005; Sun 2006).

Table 1. Timeline of Key Fire Suppression, Timber Extraction, and Cultural Fire Revitalization Events in California's Klamath Basin.

Year	Event	Source
1892	Land on the Yurok reservation is converted into private property through allotment, initiating the appropriation of Yurok land by timber companies to extract redwood	(Huntsinger and McCaffrey 1995)
1905	Klamath Forest Reserve established	(Davies and Frank 1992)
1911	Weeks Act enables cooperative fire protection between federal, state and private landholders	(Hudson 2011)
1924	Clarke-McNary Act codifies federal financial assistance to states for fire suppression	(Hudson 2011)
1933 - 1942	Civilian conservation corps builds fire look-outs, roads, and other fire suppression infrastructure across Klamath National Forest	(Davies and Frank 1992)
1940s	Cultural burning in Karuk and Yurok territory persists and frustrates Forest Service and CAL FIRE suppression forces	(Davies and Frank 1992; Conners 1998)
1945	Excess WWII military planes used to monitor fires and aid in suppression across National Forests	(Davies and Frank 1992)
1950s – 1960s	Road construction in Klamath and Six Rivers National Forests to support timber extraction	(Strothmann and Roy 1984; Conners 1998)
1969	National Environmental Policy Act codified	(Bowers and Carpenter 2011)
1975	Indian Self-Determination and Education Assistance Act codified	(Strommer and Osborne 2014)
1960s – 1980s	Gasquet-Orleans road through sacred Karuk, Yurok and Tolowa spiritual areas proposed, resisted, and litigated	(Bowers and Carpenter 2011)
1978	Creation of Redwood National Park in Yurok territory allows increased timber removal in Six Rivers National Forest	(Schrepfer 1983)
1980s – 1990s	Basketweavers establish partnerships with Forest Service staff to support cultural burning of fire-enhanced basketry resources	(Hunter 1988; Ortiz 1998)

1994	Northwest Forest Plan enacted and reduces timber extraction on National Forests	(Charnley et al. 2018)
2003	Healthy Forests Restoration Act codifies stewardship contracting and eliminates planning rules to accelerate hazardous fuel reduction and prescriptive burning	(Davis 2004)
2010	Orleans Community Fuel Reduction project destroys Karuk spiritual trails, and amplifies distrust between Tribal members and the Forest Service	(Scott-Goforth 2013; Tripp 2019)
2013	Karuk and Yurok Tribal partnerships with the Fire Learning Network initiate prescribed fire training exchanges (TREX)	(Terence 2016)
2016	MOU between Six Rivers National Forest and Karuk Tribe allows cooperative cultural burning	(T. Marks-Block, pers. obs., 2016)
2018	Somes Bar Integrated Fire Management Project, initiated by the Karuk Tribe and the Western Klamath Restoration Partnership, approved	(USDA Forest Service PSW Region 2018)
2011 - 2019	Yurok Tribe increases funding for cultural burning and land acquisitions using California carbon sequestration market (AB32) and other funding mechanisms	(Manning and Reed 2019)

CULTURAL FIRES IN KARUK AND YUROK TERRITORY: 2014 - 2019

Tribal Fire Management and Constraints to Cultural Burning

From 2014 – 2019, the Karuk and Yurok Tribes, and organizations such as the Cultural Fire Management Council (CFMC) and the Orleans Somes Bar Fire Safe Council (OSBFSC) have raised and invested considerable resources into revitalizing the practice of cultural burning and developing alternative ways to manage wildfires to limit suppression tactics. Each Tribe has established its own wildland fire team under self-governance policies that emerged from American Indian organizing in the 1970s and the passage of the Indian Self-Determination and Education Assistance Act of 1975 (Strommer and Osborne 2014; Wilkins and Stark 2017). These wildland fire teams are contracted to conduct suppression on wildfires throughout the region (Lake 2011). They also conduct cultural burning within their ancestral territories. Despite this investment, relatively little cultural burning has occurred (Chapter Five) compared with pre-colonial levels and future objectives. Therefore, to deconstruct federal and state prohibitions on cultural burning, and to disincentivize the investment in an entrenched bureaucratic infrastructure to suppress fires (Pyne 2016; Ingalsbee 2017), concerted efforts are required to establish reliable systems of cultural burning that can employ wildland fire personnel currently financially reliant on fire suppression.

In the summer of 2014 and 2017, several large lightning-ignited fires (> 40,000 ha combined) occurred in Karuk and Yurok territory that produced poor air quality and precipitated a major influx of temporary labor to minimize fire spread. Tribal staff in the Karuk Department of Natural Resources (DNR) stated that the federal response to the fires was excessive, wasteful, and destroyed culturally-important places where Tribal members hunted, gathered and conducted spiritual practices (Norgaard 2019). Recent Tribal oversight of these fire incidents has reduced the construction of destructive bulldozer lines and tree-felling in the name of fire suppression. In 2017, the Karuk wildland fire team reported that they were able to collaborate with a federal incident management team to conduct positive cultural burning near a wildfire incident to prevent wildfire spread, and to protect and enhance hardwood stands (D. Medford, pers. com., 2018). They were able to take advantage of a wildfire incident to achieve burning objectives that otherwise would not have been permitted.

Without local wildfire incidents, funds to conduct cultural and prescriptive burns on National Forest lands remain quite limited. Although the Northwest Forest Plan encouraged a transition to develop employment opportunities surrounding ecological restoration and prescriptive burning (Charnley et al. 2018), Congressional budget allocations for such projects have not increased with this policy change (Hudson 2011). Instead, these projects are often delayed because wildfire suppression costs reduce available funds for restoration (USDA Forest Service 2015). The recent 'wildfire funding fix' in the US Congress Consolidated Appropriations Act of 2018 (Taylor 2019) may be an effective budgetary mechanism that prevents wildfire costs from diminishing available funds for prescriptive fire projects. However, the persistent emphasis on timber volume sold to increase local National Forest budgets generates opportunity-costs for administrators that can lead to the de-prioritization of prescriptive burning and restoration (Hirt 1996; Schultz et al. 2015).

In the Six Rivers National Forest, funding for prescriptive and cultural burning has been inaccessible to local managers. Many planned burn sites are experiencing multi-year delays, despite the completion of all National Environmental Policy Act (NEPA) reviews. Conducting these burns remains a high priority for managers. Often, however, even when burn conditions are appropriate, budget uncertainties may influence upper management who may not make the necessary allocations. Safety policies, such as having contingency fire engines and personnel available during prescriptive burns, are often unfunded, and prevent burns from occurring. Many wildland fire staff are temporary, and agency budgets prioritize these positions during the peak of the wildfire season when prescriptive burning is less likely to occur. From 2017 – 2019, wildfires in other Californian regions precipitated an additional constraint, as CAL FIRE and Forest Service leadership imposed state-wide bans on prescriptive burning, despite excellent controlled burning conditions in Karuk and Yurok territory.

The communities of Orleans and Somes Bar are particularly susceptible to Forest Service delays in prescriptive burning because they are surrounded by National Forest lands. In response, the Karuk Tribe and the OSBFSC have organized to co-lead the Western Klamath Restoration Partnership (WKRP), to conduct prescribed fire restoration and fuel reduction treatments on local National Forest lands (Vinyeta and Lynn 2015). The Karuk Tribe and OSBFSC also lead annual prescribed fire TRaining EXchanges (TREX) in collaboration with The Nature Conservancy and governmental agencies to support burning on privately owned parcels (Harling 2015; Spencer et al. 2015; Terence 2016). The increase in prescriptive burning on private parcels is partially intended to create a buffer between these residences and the national forest lands to reduce wildfire risk. TREX has helped generate trust among agencies as agency representatives all collaborate on burning and gain expertise in using the federally mandated incident command structure. The successful implementation of prescriptive burns under this model has allowed the Tribe and OSBFSC to leverage more funding through CAL FIRE and federal sources to develop a year-round prescriptive fire crew in the region that can be made available to the USDA Forest

Service and private landowners. The WKRP plans to use this crew to support the implementation of prescriptive burning on a pilot Forest Service restoration project in the Somes Bar area (USDA Forest Service PSW Region 2018).

Contradictions of Cultural Burning

Through partnerships like the WKRP, the Karuk and Yurok Tribes have become quite adept at integrating Indigenous objectives into Western forest and fire management. Tribal expertise in management has allowed them to gain power and input over decision-making within bureaucracies that formerly had little community or Tribal oversight. Although fire management provides Tribal members with a source of income and moves Tribes toward their longer-term objectives of increasing cultural burning, these institutionalized management activities also detract from cultural and subsistence practices. Many Tribal members lament that their wage work reduces their time to gather and hunt traditional foods and materials (Norgaard 2019; Sowerwine et al. 2019). Fire management generates a dialectic between the bureaucratic and managerial procedures necessary to increase fire on the landscape, and the livelihoods that cultural burning intends to support (Nadasdy 1999; Fache and Moizo 2015; Petty et al. 2015). These dynamics are indicative of what Anna Tsing calls a 'pericapitalist space'—where individuals are engaged in capitalist and non-capitalist forms of subsistence (Tsing 2015), and what Jon Altman describes as a 'hybrid' Indigenous economy (Altman 2009). Tribal members say it would be foolish to rely only on wages given the inherent economic declines built into capitalism and the dependency on Congressional appropriations to sustain Tribal governance structures. Hence, it is common to find Tribal members who, in addition to wage work and traditional subsistence, are also engaged in growing *Cannabis* for additional cash income.

Northern Humboldt County, which encompasses much of Yurok territory and the southern half of Karuk territory, is known for its liberal politics, and has long attracted left-leaning non-native counter-culturalists who oppose logging and sustain themselves by growing *Cannabis* (Salter 1982; Leeper 1990; Norgaard 2007). Since the statewide legalization of medical (1996) and recreational (2016) *Cannabis*, Humboldt County has created one of the least restrictive ordinances governing *Cannabis* cultivation. The growth of large, industrial-scale *Cannabis* cultivation has come into conflict with the Tribes and others concerned about its environmental impacts (Bauer et al. 2015; Butsic et al. 2017). These large *Cannabis* growers and their employees are also transient, and typically do not engage in socio-ecological restoration projects led by the Tribes. However, there are also longer-term and smaller-scale non-native *Cannabis* growers and workers in the community. As noted by one Karuk Tribal member, the flexible working hours of this ‘weed economy’ have allowed many to volunteer and support cultural burning efforts. Hence, the *Cannabis* economy contributes to a hybrid, peri-capitalist economy, and the culture associated with *Cannabis* farming facilitates cultural burning and Indigenous modes of subsistence.

Among some Tribal members skepticism remains that state-sanctioned burning will meet their objectives, and thus, ‘renegade’ burning, an emic term for what the state refers to as ‘arson’, is a parallel practice to increase the area and frequency of cultural fires. Renegade cultural burning was quite common during my five years of field work in Karuk and Yurok territory. Renegade burning included burning wood piles without a permit, broadcast burning adjacent to recent state-sanctioned burns to safely expand existing burned areas, burning under the cover of night to reduce the risk of getting caught, and setting fires with no intention of limiting their spread. Under ideal conditions, many experienced fire lighters can burn a few hectares by themselves or with another person. This ‘renegade’ burning practice is significantly more affordable and expedient when compared with the bureaucratic processes imposed by the federal and state governments. Like sanctioned cultural burns, renegade burns have specific resource objectives that range from improving basketry materials and deer forage to producing sufficient smoke to reduce river temperatures for fish. Although there is frustration toward individuals who ignite renegade burns that turn into large wildfires, many Tribal members understand the motivation, and only wish the fires were set more strategically so that they prompted less state scrutiny and home destruction.

In August 2016, several renegade fires that threatened homes were set along the main thoroughfare on the Yurok reservation. These fires precipitated destructive suppression tactics that harmed a gathering area for beargrass (*Xerophyllum tenax*), an important basketry material. Later in September 2016, the Cultural Fire Management Council (CFMC) was prepared to initiate the Yurok TREX that would bring fire professionals from across the West Coast to help them conduct cultural burns. A light drizzle the previous day had moistened the forest canopy and one of the leaders of CFMC said that these were perfect conditions for burning the understory. However, CAL FIRE stated that they would only grant a burn permit if there was one tenth of an inch of rain, as they were concerned about the risk of a fire escape. To many, this fire permit denial was perceived as retribution for the August renegade fires because no one reported the ‘arsonist’. Thus, these renegade fires seemingly created difficulties for those attempting to build trust and collaborations with the state for future negotiated autonomous burning.

In the following spring 2017, a temporary compromise emerged through the efforts of the CFMC. Not only did CAL FIRE approve a grant for burning on the reservation, but they also agreed to join the burning efforts by providing personnel and equipment. Far from an anti-fire behemoth, there are many within the CAL FIRE organization that support prescriptive burning. One CAL FIRE middle manager stated that he learned the importance of cultural burning long ago from the Yurok friends he made while studying at Humboldt State University, and he was proud to light fires alongside them.

The Future of Cultural Fire

Although the goals of the Forest Service may have expanded to include multiple objectives (including ecological restoration), timber extraction for profit remains a prominent objective that, as practiced, is not aligned with other objectives (Hudson 2011). Prescriptive burning and timber extraction are no longer seen in opposition by government agencies, in contrast to the initial decades of California forestry (Show and Kotok 1924; Clar 1959). Moreover, the passage of the Healthy Forests Restoration Act in 2003 was strongly supported by timber companies, and provided funds for fuel reduction methods such as prescriptive burning (Sun 2006). Timber companies and the Forest Service now agree that burning improves timber stands and protects them from wildfire. However, the expansion of prescriptive burning by the Forest Service may prove to be yet another subsidy for timber interests that deprioritizes the other eco-cultural benefits of low-intensity fire.

Prescriptive burning by timber companies in this region largely ceased by the 1990s because of increased liability risks and air quality concerns. But the grassroots resurgence of prescriptive burning with support from CAL FIRE indicates to timber companies that they may be allowed to re-introduce such burning practices to their timber holdings. The appropriation of prescriptive burning for these commercial purposes concerns Tribal members who do not want to be perceived as complicit with the timber industry. Nonetheless, colonial and Tribal government fire management tactics are now more aligned than ever before, and with federal and state regulations requiring Tribal consultation (Dockry et al. 2017; Long et al. 2018b), Tribes are capitalizing on their political position to gain increased autonomy over fire management.

In Karuk and Yurok territories, the larger issue of land dispossession and colonialism remain at the core of the challenges related to expanding prescriptive burning. Many Karuk and Yurok families would like to increase the proportion of fire-enhanced resources in their diets to improve health and maintain spiritual connections with the land and their ancestors (Norgaard 2019; Sowerwine et al. 2019). However, in Karuk territory, most of the land is controlled by the USDA Forest Service, and the majority of private property is no longer in the possession of Karuk families. On the Yurok reservation, ~50% of all property is now owned by private timber companies, and many families have lost their allotments through fraud or their properties are highly fractionated and difficult to manage (Shoemaker 2003; Carroll et al. 2010; Huntsinger and Diekmann 2010; Yurok GIS Program 2015). Tribal members who do not own property or have access to allotments cannot gain as many benefits as those who own properties and can directly benefit from TREX burns. Setting a fire on traditional hunting and gathering tracts that are now under Forest Service or private timber company jurisdiction remains high risk as it can result in expensive fines and imprisonment. Because prescriptive burning is such a highly regulated practice, and land is in such low supply, Tribes primarily have used legal avenues to expand burning.

Reflecting on the use of cultural fire today, as opposed to during the height of fire suppression (e.g., 1920 – 1970), Chook Chook Hillman (Karuk) states:

> Maybe they could have continued to do ceremonial fire, but I wouldn't have been here today because they would have been rubbed out or doing 40 years in prison for arson…I'm not going to see the results of my work [today], and that's okay, because we don't do it for ourselves, we do it out of this responsibility…I'm doing it because that's my job as a Karuk person (Muldavin 2019: 06:32-06:40, 07:23 - 07:39).

Although the extent of cultural burning is limited at present, Chook Chook recognizes that his actions to expand cultural burning within the current political framework is strategic, and will facilitate expanded autonomy in future generations. Although cultural burning during ceremonies has not yet been revitalized, the preparations are underway (USDA Forest Service PSW Region 2018: 18).

In Karuk territory, developing partnerships with the USDA Forest Service has been the most effective activity to expand cultural burning. In the past decade the Forest Service has become more accommodating and cooperative toward planning and conducting cultural burns on lands under their jurisdiction. In 2016, the Karuk wildland fire crew was able to conduct a cultural burn alongside a Forest Service wildland fire crew for the first time with a Memorandum of Understanding (MOU) between both governments. This MOU was an important step for the Tribe to increase their ability to burn in their ancestral territory and required several years of administrative negotiations. Additionally, there are Karuk Tribal members have been organizing with non-native residents to call for the return of privately owned properties to Indigenous families to support Indigenous land management and livelihoods (Hurwitz and Bourque 2018). Other non-native residents in Karuk territory are actively involved in the OSBFSC, and either volunteer or are paid to support Tribally led fire restoration projects.

The Yurok Tribe has been purchasing property in their ancestral territory using a diverse funding strategy that includes carbon offset funds from California's AB32 carbon emissions market (Manning and Reed 2019). The Tribe intends to use cultural burning in these areas to both restore the landscape and sequester carbon. However, participating in the cap and trade program has been controversial. The carbon market allows companies to pay offsets for their carbon emissions, and climate justice organizations believe this negatively affects adjacent communities and does not do enough to reduce carbon emissions (Blanchard and Vira 2017). Furthermore, some Tribal members worry that the restrictions governing these carbon sequestration agreements will preclude the restoration of non-forested prairies and savannas.

The Tribe has also been working with their Congressional representative to pass legislation that would expand their reservation by, in part, re-patriating a USDA Forest Service research forest known as the Yurok experimental forest (Mukherjee 2019). These actions and proposals are well within US federal law, yet they are advocating for greater Tribal sovereignty and funding allocations from Congress to benefit Tribal communities that have been marginalized by colonial policies (Myers 2019).

Cultural burning is a critical component of a broad movement toward Tribal sovereignty through cultural revitalization (Hillman and Salter 1997; Simpson 2011; Carroll 2015). Therefore, cultural burning faces challenges similar to those of Indigenous struggles worldwide that are subverted through resource extraction and white supremacy (Moreton-Robinson 2015; Lightfoot 2016; Estes 2019). This exploitative colonial strategy has produced dire social, economic, and health outcomes for Karuk and Yurok Tribal members (George 2017; Norgaard 2019). These circumstances have engendered the use of multiple strategies to regain autonomy and self-sufficiency. Some of these strategies include developing self-governance contracts with the Bureau of Indian Affairs and other federal agencies to provide health care and other basic needs to Tribal members in remote areas (Strommer and Osborne 2014). Providing fire protection and developing forestry departments is a means by which Tribes can exercise self-governance within the framework of federal Indian law (Harris et al. 1995; King 2007). The Bureau of Indian Affairs has no expectations or requirements that Tribal wildland fire departments initiate cultural burning, yet the Karuk and Yurok Tribes have done just that. Inevitably, internal Tribal politics regarding how these departments function and use resources remain contentious (Carroll 2015).

Although strong arguments and views persist that Tribal and First Nation engagement with colonial structures co-opt and subvert Tribal autonomy (Allred et al. 2011; Coulthard 2014; Simpson 2017), individuals and groups working within these structures may also facilitate forms of governance that are aligned with decolonization (Carroll 2015). Karuk and Yurok Tribal members recognize the persistent hegemonic power held by the US government, yet believe possibilities exist for inserting relational forms of thinking into federally-mediated self-governance institutions and collaborations (Carroll 2015). Although there is a threat of co-optation (Nadasdy 1999), participants in these collaborations believe that cultural burning helps build alliances and solidarity from non-native communities that will contribute to long-term victories against colonial governance. Karuk wildland fire leader Herman Albers states that “we have 1.2 million acres that we want to treat and restore and we can’t do it alone. If we are trying to do it ourselves it’s going to take too much time” (Muldavin, 2019: 03:39 - 03:48).

Indigenous resistance against fire exclusion and land dispossession in Karuk and Yurok territories has taken many forms since the state of California and National Forests were established. To ensure the persistence of cultural burning, Tribal members have engaged in renegade burning, informal collaborations with US Forest Service and CAL FIRE staff, and formal partnerships between Tribal and land management agencies. These multiple modes of resistance have all increased support and awareness of cultural burning across diverse jurisdictions. Currently, Tribes and Tribal members are positioned to expand cultural burning with the broad support of non-native residents, government staff, and elected officials. This expansion of cultural burning will undoubtedly benefit future generations of Indigenous and non-Indigenous Californians and their non-human relations.

CHAPTER 3

Effects of Understory Fire Management Treatments on California Hazelnut, an Ecocultural Resource of the Karuk and Yurok Indians in the Pacific Northwest.

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ABSTRACT

Before widespread fire exclusion policies, American Indians used broadcast understory fires or cultural burns to enhance resources integral for their livelihood and cultural practices. To restore ecocultural resources depleted from decades of fire exclusion and to reduce wildfire risks, the Karuk and the Yurok Tribes of Northwest California are leading regional collaborative efforts to expand broadcast fires and fuel reduction treatments on public, private, and Tribal lands in their ancestral territories. Through collaboration with Karuk and Yurok Tribal members and basketweavers, we evaluated the effects of broadcast fires and three fire proxy treatments on California hazelnut shrubs (*Corylus cornuta* var. *californica*) that produce highly valued ecocultural resources for basketry materials. Across a 10 ha Douglas-fir and mixed hardwood forest (500 m a.s.l.) in the Klamath mountains, we established 27 stratified blocks (16 m^2) and within each block applied three fire proxy treatments designed and used by Tribal members with an untreated control. These treatments involved manual hazelnut stem cutting, directly blistering hazelnut stems via propane torch, and igniting surface fuels piled within hazelnut shrubs to top-kill stems. Broadcast fire was applied to 12 separate blocks. After a full growing season (12 - 18 months post-treatment/burn), shrubs were re-measured. We then harvested these stems (n=604; 50 shrubs) across treatments and compared results with stems gathered independently by two experienced Karuk/Yurok basketweavers (n = 396 and n = 73) from an adjacent broadcast burned site. Compared to the untreated shrubs, pile burning, propane torching, and broadcast burning increased basketry stem production by 7 to 10 fold ($p < 0.001$), while the cutting treatment increased production by 4-fold ($p = 0.006$). Shrubs with relatively greater access to sunlight (southern aspect, $\geq 51\%$ and $< 70\%$ canopy cover) produced fewer quality stems when compared to shrubs with an eastern aspect ($p < 0.01$) and $\geq 70\%$ canopy cover ($p < 0.05$). Harvested stems

across all treatments displayed similar stem length distributions to those gathered by one of the two basketweavers ($p > 0.05$). Our results demonstrate that these fire-proxy methods are an effective means to increase the production and quality of basketry materials. Expanding the area and frequency of targeted understory fire-based forest treatments on private, public and Tribal lands in California and the Pacific Northwest would substantially increase the availability of these fire-enhanced ecocultural resources that are currently limited in supply and in high demand.

INTRODUCTION

As a result of historic fire exclusion policies in the American West, American Indian communities have sought to re-integrate prescribed fire and other fuel reduction treatments to decrease wildfire risks on Tribal lands and across other jurisdictions within their ancestral territories (Carroll et al. 2010; Long and Lake 2018; Kolden 2019). Tribes have expressed strong interest to use prescribed fire to improve the density and availability of culturally and economically important plants, fungi, and animals, referred to as 'ecocultural resources' (Carroll et al. 2004; Lake et al. 2017; Anderson 2018; Long and Lake 2018). Although ecocultural resources are similar to nontimber forest products (Charnley et al. 2007; Jones and Lynch 2007; Chamberlain et al. 2018), ecocultural resources are also integral to Indigenous identity (Kimmerer 2011; Long et al. 2018b).

Co-management agreements between Tribes and public land agencies, such as the United States Department of Agriculture (USDA) Forest Service, reflect recent efforts to integrate Tribal ecocultural resource objectives into management plans (Carroll et al. 2010; Donoghue et al. 2010; Bussey et al. 2015; Catton 2016; Diver 2016; Dockry et al. 2017; Jurney et al. 2017; Long and Lake 2018). Although numerous studies exist on the effects of prescribed fire, along with manual, mechanical, and pile burning fuel reduction treatments on fire severity (Kalies and Kent 2016), only a few studies in North America examine the effects of such treatments on ecocultural resources (Lathrop and Martin 1982; Lake 2007; Shebitz et al. 2009; Hankins 2013; Halpern 2016; Peter et al. 2017; Wynecoop et al. 2019). Given that pre-colonial Indigenous burning, coppicing, transplanting, and harvesting sought to enhance ecocultural resources, specifically examining how such treatments affect these resources may provide useful information to support the objectives of Tribes and land management agencies involved in ecological restoration, socio-economic development, and wildfire risk reduction (Senos et al. 2006; Kalies and Kent 2016; Anderson 2018; Charnley et al. 2018).

After several decades of limited fuel treatments, the Karuk and the Yurok Tribes in Northwest California are leading regional efforts to expand fuel reduction treatments and prescribed fires on public, private, and tribal reservation lands in their ancestral territories to protect structures and to restore ecocultural resources (Fig. 3A; Diver, 2016; Harling, 2015; Long et al., 2018; Robbins et al., 2016). Fire-enhanced ecocultural resources (e.g., acorns, berries, basketry materials, and wildlife) are integral to the Karuk and Yurok Tribes (Harrington 1932; Heffner 1984; Huntsinger and McCaffrey 1995; Baldy 2013; Norgaard 2014). In Karuk and Yurok territory, and elsewhere in California, American Indians refer to their prescribed fires as 'cultural burns', because the burns aim to improve the qualities and densities of ecocultural resources central to subsistence and ceremonial practices (Aldern and Goode 2014; Long et al. 2018b). Cultural burning is a critical component of 'ecocultural revitalization' efforts in Northwest California given the centrality of fire-enhanced resources to cultural practices. Cultural burning distinguishes these fires from the fuel reduction-focused prescribed burns of public land agencies whose primary objective is to reduce fuel loads, and thus, moderate wildfire intensity (Schwilk et al. 2009; Collins et al. 2010).

Since the early 1990s, forest management in the Pacific Northwest and Tribal consultation policies have undergone several major conceptual and programmatic changes coupled with legislation (Thomas et al. 2006; Vinyeta and Lynn 2015). American Indian political organizing resulted in the passage of legislation to reform the National Historic Preservation Act in 1992 that required US governmental consultation with Tribes surrounding cultural resources in their ancestral territories (Stapp and Burney 2002). In 1994 and 2000, US President Clinton issued executive orders that expanded consultation requirements to all decisions that had implications for Tribes (Clinton 1994, 2000). These executive orders along with other internal actions of USDA Forest Service staff catalyzed the hiring of Tribal liaisons and the formation of the Office of Tribal Relations (Catton 2016). Consequently, to meet these treaty and federal Indian trust obligations, collaborations among Tribes and public land agencies became increasingly formalized (Lake et al. 2018; Long et al. 2018b).

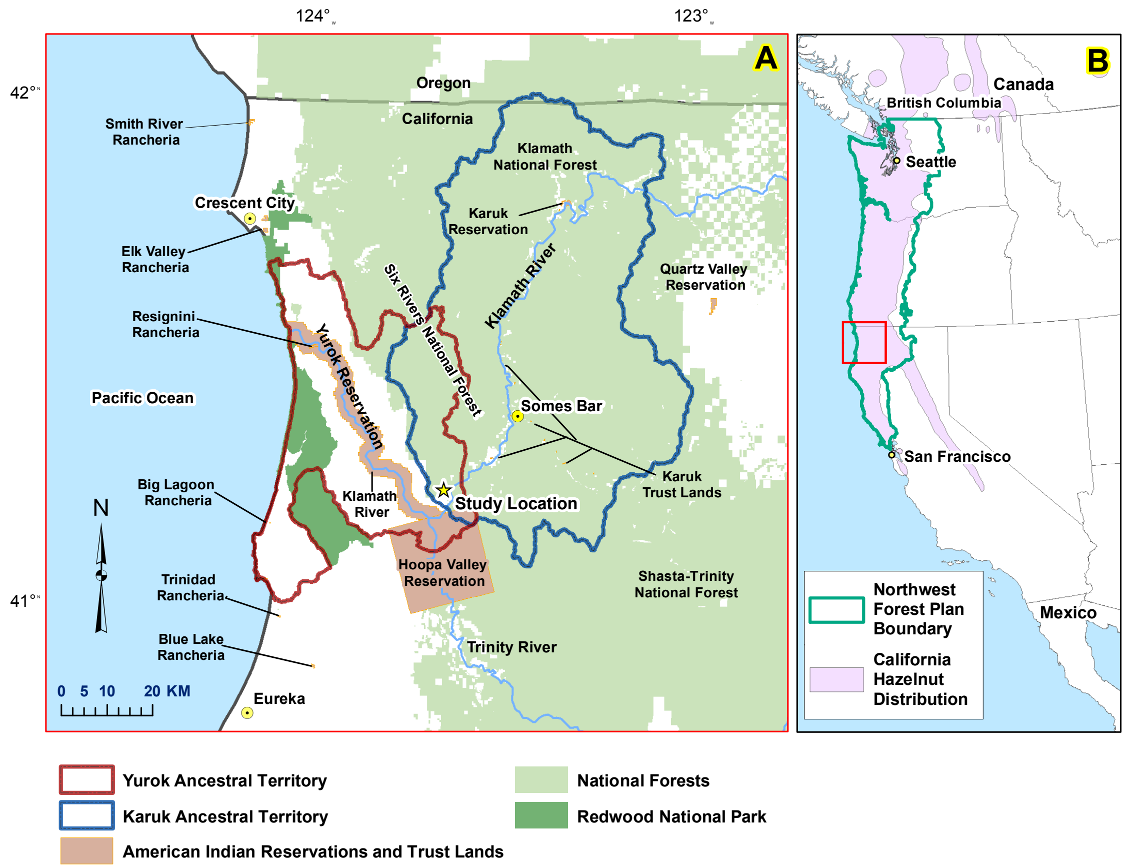

Figure 3. (A) Study region with federal jurisdictional boundaries and Karuk and Yurok territories. Ancestral territory boundaries, provided by the Karuk and Yurok Tribes, represent reconstructions, but currently are not fixed or rigid boundaries. Ancestral lands of other Northwest California Tribes (e.g., Tolowa, Wiyot, Hupa, Shasta) are not included here, but note that their ancestral lands may partially overlap with the boundaries rendered here (Baumhoff 1963). **(B) Western Region of the United States of America, including California hazelnut (Corylus cornuta var. californica) distribution derived from the Atlas of US Trees (Little Jr 1971) as well as the area encompassed under the Northwest Forest Plan (2002).** The study region is depicted by the red square.

With the implementation of the Northwest Forest Plan (NWFP) in the 1990s (Fig. 3B), forest management on public lands in Karuk and Yurok ancestral territories shifted from timber extraction toward ecological restoration and endangered species conservation (e.g., Northern Spotted Owl, *Strix occidentalis*) dependent upon old-growth forests (Thomas et al. 2006). The NWFP also precipitated the development of new National Forest plans and established regular federal monitoring of Tribal consultation processes that created opportunities for the Karuk Tribe to influence forest policy and resource management within their ancestral territory (Senos et al. 2006; Vinyeta and Lynn 2015; Diver 2016; Long et al. 2018b). These policy changes as well as the 2001 National Fire Plan and the 2003 Healthy Forests Restorations Act established benchmarks and best practices coupled with earmarked funds for fuel reduction treatments, and supported collaborative projects to manage fire in Karuk and Yurok ancestral lands (Lake 2011). In California and the Pacific Northwest, the USDA Forest Service annually treats more area with understory mechanical thinning than prescribed fire to reduce forest surface fuels (Vaillant and Reinhardt 2017). Impediments to prescribed fire and fuel reduction include seasonal restrictions on fuel reduction activities for threatened and endangered wildlife, staff reductions associated with the decrease in timber receipts from NWFP mandates, burn restrictions during major wildfire events, and air quality regulations that constrain available burn days (Williams 2009; Quinn-Davidson and Varner 2012; Calkin et al. 2015; Stephens et al. 2016; Schultz et al. 2018). However, recent efforts within the USDA Forest Service to increase cross-jurisdictional landscape-scale treatments, known as the 'Shared Stewardship' initiative seek to address several of these constraints (USDA Forest Service 2018).

Despite these challenges, the Karuk and Yurok Tribes collaborate with the Fire Learning Network (FLN) and other agencies to host annual prescribed fire training exchanges (TREX: Butler and Goldstein, 2010; Harling, 2015; Long et al., 2018; Robbins et al., 2016; Spencer et al., 2015). The FLN is an effort by the USDA Forest Service, US Department of the Interior, and The Nature Conservancy to restore fire-dependent landscapes by engaging in collaborative, community-based planning. On the Yurok reservation, the Cultural Fire Management Council (CFMC) leads efforts to expand cultural burning in partnership with the Yurok Tribe and the California Department of Forestry and Fire Protection (Yurok Tribe 2015). CFMC is a community-based organization led by Yurok Tribal members that support private and Tribal landowners who seek to conduct cultural burns on their properties by sharing equipment, providing necessary personnel, and submitting permits. The Karuk Tribe is collaborating with the USDA Forest Service, the Orleans-Somes Bar Fire Safe Council, and other community organizations to initiate fuel reduction and cultural burn treatments in their territory through the Western Klamath Restoration Partnership (WKRP; Lake et al., 2018; Long et al., 2018; USDA Forest Service PSW Region, 2018; Vinyeta and Lynn, 2015). The WKRP is composed of NGOs, Tribes, and government agencies that have initiated a pilot project near Somes Bar, CA to apply mechanical and prescribed fire treatments in fire excluded forests. Upon completion, they have proposed to expand these fire treatments across 480,000 ha. (Lake et al. 2018; Long et al. 2018b; USDA Forest Service PSW Region 2018).

Substantial ethnohistorical information exists on the effects of fire on ecocultural resources worldwide (Scherjon et al. 2015; Trauernicht et al. 2015) and in the Pacific Northwest, and California, in particular (Blackburn and Anderson 1993; Lewis 1993; Boyd 1999; Anderson 2005). However, empirical ecological effects of contemporary fuel reduction treatments on ecocultural resources are not well known, and such studies may serve to inform adaptive and collaborative management projects in American Indian territories (Berkes et al. 2000; Anderson 2002; Long et al. 2018b; Wynecoop et al. 2019). Species-specific studies have demonstrated that prescribed burning improves the densities of blueberries (*Vaccinium* spp., Duchesne and Wetzel, 2004) and reduces insect infestation in tanoak acorns (*Notholithocarpus densiflorus*, Halpern, 2016). Fire has been shown to increase the density and enhance the quality of several plant species (e.g., *Xerophyllum tenax* beargrass, *Muhlenbergia rignes* deergrass, *Anthoxanthum nitens* sweetgrass) used for American Indian basketry resources (Lathrop and Martin 1982; Anderson 1999; Shebitz and Kimmerer 2005; Griffith et al. 2007; Gagnon and Platt 2008; Shebitz et al. 2009; Peter et al. 2017; Hart-Fredeluces and Ticktin 2019).

California hazelnut (*Corylus cornuta* Marsh. var. *californica*) is a critically important ecocultural resource for Karuk and Yurok Tribal members. California hazelnut ranges from British Columbia to the southern Sierra Nevada and central coastal mountains of California and extends over ~76% (180,471 km^2) of the NWFP area (Fig. 3B; Little Jr, 1971; Thompson et al., 2015). California hazelnut is a deciduous, multi-stemmed shrub that resprouts vegetatively after disturbance, similar to *Corylus americana* and *Corylus cornuta* var. *cornuta* in central and eastern North America (Buckman 1964; Pelc et al. 2011). Throughout California hazelnut's range, the nuts are consumed by American Indians (Thompson 1991; LaLande and Pullen 1999; Cuthrell 2013; Fine et al. 2013; Armstrong et al. 2018). Across the Pacific Northwest, California hazelnut stems continue to be used by American Indians for basketry and material culture (Mason and Coville 1904; Moerman 1998; Turner 1998; Zobel 2002) with similar uses of *Corylus* spp. persisting throughout Europe (Bichard 2008; Batsatsashvili et al. 2017). The straight and unbranched stems of recently burned hazelnut shrubs are in high demand by California Indians to produce baskets for diverse uses (Fig. 4, Anderson, 1999; Bibby, 2004; Harrington, 1932; Heffner, 1984; Hunter, 1988; Johnson and Marks, 1997; Kallenbach, 2009; Levy, 2005; Mathewson, 2007; O'Neale, 1932; Ortiz, 1998, 1993; Salberg, 2005; Shanks, 2006; Thompson, 1991; Underwood et al., 2003). In 2017, basketweavers reported hazelnut stems selling for $1 per stem, indicating their socio-economic value (T. Marks-Block, pers. obs., 2018). Moreover, the diverse products constructed from these materials reflect their artistry skills, cultural significance, and ancestral history and identity as well as bestow respect for these talented basketweavers (Johnson and Marks 1997; Mathewson 1998; Bibby 2012). One type of basket in high demand is the baby cradle as these cradles remain a central component of child rearing in Northwest

California Indian culture (Bibby 2004). These baskets often require ~300 hazelnut stems to produce and then may be sold for ~$800 dollars (T. Marks-Block, pers. obs., 2018).

Based on ethnographic studies, Northwest California Indians such as the Karuk and Yurok reportedly initiated relatively small (<4 ha) understory broadcast fires in the summer and fall months every 2 – 5 years in hazelnut groves to increase concentrations and quality of basketry stems (Harrington 1932; Thompson 1991; Huntsinger and McCaffrey 1995; LaLande and Pullen 1999; Stewart 2002; Anderson 2005; Busam 2006). As cultural burning diminished due to the enforcement of fire exclusion policies, basketry stems reportedly became scarce because only poor quality gathering areas remained that, in turn, highly constrained basketry production (O'Neale 1932; Bright 1957; Heffner 1984; Huntsinger and McCaffrey 1995; Levy 2005; Norgaard 2014). For example, based upon 43 interviews with basketweavers in 1929, anthropologist Lila O'Neale reported that:

> Hazel sticks are conceded by the women of both tribes [Yurok and Karok] to be the best, but the most difficult to procure nowadays. New little shoots from a ground recently burned over are ideal. This statement is followed, however, by the lament that fires cannot be set as they used to be by the old-time weavers, and by the regret that accidental burnings occur seldom in places where they do basket makers any good (O'Neale 1932:15).

Because of these resource availability challenges, basketweavers and stem gatherers have used permitted techniques to generate hazelnut re-sprouting that serve as substitutes or proxies for cultural burns (F. Lake, pers. obs; Hunter, 1988).

To evaluate these techniques for potential inclusion into larger-scale fuel reduction management areas, we collaboratively designed a field experiment to compare the efficacy of four practices (Fig. 5) used by Yurok and Karuk Tribal members to increase hazelnut stems for basketry: 1) cutting or the manual coppicing of hazelnut shrubs (Hunter 1988); 2) pile burning of surface fuels including needle/leaf litter and 1-hour (0.00-0.64 cm diameter) and 10-hour (0.64-2.54 cm diameter) fuels within individual hazelnut shrubs; 3) propane torch burning of individual hazelnut shrubs (Ortiz 1998); and, 4) prescribed cultural burns set to broadcast, or move through the understory, to top-kill multiple hazelnut shrubs. Among these treatments, we compare and contrast the production of suitable shoots: straight, unbranched basal re-sprouts of hazelnut shrubs (Fig. 4). Then we evaluate if canopy cover, aspect, and the presence of deer browse influence the productivity of basketry stems. Basketry stems were harvested post-treatment and compared and then contrasted by length and diameter with stems harvested independently by two experienced Karuk/Yurok basketweavers from an adjacent broadcast burned site.

Figure 4. Hopper Basket (center) Used to Pound Acorns with Unpeeled (left) and Peeled (right) Hazelnut Basketry Stems. This basket is composed of peeled hazelnut stems similar to those shown along with other materials. Photo: Frank Lake, USDA Forest Service and Karuk Tribe.

Figure 5. Four Hazelnut Shrub Treatments. (A) Pre- and post-cut treatment. All stems in each shrub were cut to ground level (<5 cm) to stimulate coppicing, and to mimic mechanical understory clearing and piling for fuel reduction. (B) Pile burn treatment during combustion. Surface fuels (primarily 1-hr, 10-hr fuels, and surface litter comprised of conifer needles and hardwood/shrub leaves) were placed between hazelnut stems within a shrub to form a burn pile (<25 cm height). (C) Propane torch burn treatment. Hazelnut shrub stems were burned at ground level to cause bark blistering and stem mortality. (D) Broadcast burn treatment. A fire was set with drip torches to back down-hill and allowed to spread to kill above-ground hazelnut stems.

These treatments and measures were conducted in direct collaboration with Karuk and Yurok basketweavers whose ecological knowledge and harvesting practices informed this study and sampling design (McLaughlin and Glaze 2008; Lake 2013). Basketweavers have observed that hazelnut shrubs that grow in areas with relatively greater sun exposure produce extensive lateral branching, thus reducing viable basketry stems post-treatment (Johnson and Marks 1997; Mathewson 1998; Ortiz 1998), but may increase nut production. Basketweavers also report that stem sprouts from coppiced hazelnut are not as pliable as stem sprouts that emerge from burned hazelnut (F. Lake and T. Marks-Block, pers. obs.). While we did not evaluate this stem characteristic, Rentz (2003) demonstrated that burned hazelnut stems contained a greater wood-to-pith ratio than unburned, coppiced hazelnut stems, lending empirical support to basketweavers' observations. Because basketweavers and managers have also reported that deer and elk browse may negatively affect basketry production (Underwood et al. 2003), we also included the presence of this activity in our observations.

Our study combines Indigenous ecocultural and 'western' scientific epistemologies to monitor and manage forests as advocated by American Indian fire and forest managers (Mazzocchi 2006; Mason et al. 2012; Lake et al. 2017). This integrated participatory approach seeks to identify effective practices for improved ecocultural resource management, such as enhancing both the density and quality of basketry materials (Emery et al. 2014; Bussey et al. 2015; Hummel and Lake 2015; Mockta et al. 2018).

METHODS

Social science methods

To develop an ecological research project focused upon an Indigenous ecocultural resource, we initially drew from Indigenous and anthropological research methods such as participatory and reciprocal study design and observations that serve to foster relationships of trust among academics, Indigenous scientists, and cultural practitioners (Smith 1999; Wilson 2008; Bernard 2011; Lake et al. 2017). We worked with Tribal cultural practitioners and Tribal government staff over several years to integrate ecocultural resource objectives into land management plans. This investment and participation in the community generated trust and led to accountability, reciprocity, and collaboration among researchers and Tribal members (Lake 2013). The collection of qualitative and quantitative social science data was developed and reviewed iteratively by as the Karuk and Yurok Tribes, who have their own independent research review processes to generate accountability and collaboration with researchers (Sarna-Wojcicki

2014; Karuk Tribe et al. 2017). These proposals then received approval by our institutional human subject review boards at the Oregon State University and Stanford University.

Sampling design and implementation initially was informed by semi-structured interviews, participant observations and collaborative field work with Karuk and Yurok basketweavers and cultural practitioners conducted by Lake (2002 - 2008; Lake, 2007; McLaughlin and Glaze, 2008). Initially, Lake worked closely with key basketweavers to develop research objectives and accountability. Building on collaborations established by Lake, Marks-Block conducted ecological field measurements from 2014 – 2019 of cultural burns (n = 15) for hazelnut stem production supplemented by additional interviews and direct observation of basketry stem gathering with basketweavers (n = 44) that informed the analyses and interpretation of the treatment data.

Our interviews and interactions with basketweavers corroborated that suitable basketry stems were scarce due to fire exclusion (Heffner 1984; Hunter 1988; Ortiz 1998). Interviews also confirmed that in the absence of broadcast burning, basketweavers and friends gathered hazelnut stems from shrubs treated using the three fire treatment proxies (Fig. 5), although the relative efficacy of these treatments remained unclear. Basketweavers also consistently recalled that the departure of supportive USDA Forest Service managers created major set-backs, because they had to re-establish lines of communication with new staff and inform them about their basketry materials and fire treatment needs. Hence, as the National Fire Plan (2001) and the Healthy Forests Act (2003) initiated increased fuel reduction treatments throughout this region (Schoennagel et al. 2009), basketweavers and Tribal members often were not informed about the schedules or locations of understory mechanical treatments and broadcast burns, and thus they missed opportunities to gather hazelnut stems. As a result, basketweavers and collaborators believed that an empirical study on the effects of several fire treatments on hazelnut shrubs could assist managers in incorporating Indigenous resource objectives into their plans.

To evaluate what basketweavers consider to be stems of basketry quality, we attended over 50 basketry classes and workshops supported by the Karuk and Yurok Tribes where we received direct instruction from basketweavers. We also observed over 50 independent hazelnut stem gathering trips to describe stem gathering practices. In these settings, all basketweavers stated that stems must be straight, unbranched, and free of insect intrusions or bark blemishes. Moreover, a wide range of both stem lengths and diameters are used depending on the type and size of basket they are weaving. Stems having lengths (e.g., 10 – 50 cm) can be used to weave earrings, tobacco pouches, or baby rattles, whereas longer stems (e.g., 50 – 100 cm) are suitable for producing storage baskets or baby cradles. Small diameter stems (1 – 3 mm) are preferred by basketweavers conducting fine weaving, although the tapered tips of long stems with 4 – 12 mm diameters may be used for similar purposes. Other basketweavers may select wide stems (5 – 12 mm diameter) for fish traps, storage baskets, or baby cradles.

As participant observers in both material gathering and production, we documented basketweaver gathering site preferences and also constraints such as gathering in marginal locations (e.g., clear cuts and mechanically thinned roadsides). Basketweaver Mrs. Verna Reece stated : "it's kind of hard to get burn[ing done]…When logging…they just burn [slash]…so it wasn't that good of material…Out in the open…[hazel stems are] kinda stalky, fat. It's different when you have…a canopy over it. It kind of reaches for the sun and kinda grows long, slender" (Lake, 2007: 600).

From these basketweaver observations, we then broadly defined suitable quality basketry stems, and focused our efforts on measuring the length and diameters of stems produced from multiple treatments under a suite of biophysical conditions. Hazelnut morphology, structural integrity, autecology, and basketry use criteria garnered from basketweavers informed the sampling design, treatments, and measurements used here (Fig. 6).

Figure 6. Karuk Basketweavers Ms. Janet Morehead (left) and Ms. Lillian Rentz (right), Peeling and Evaluating the Quality of Hazelnut Stems Gathered from the Treatment area.

Experimental methods

Study Area

Treatments were conducted on a 10 ha forest with abundant hazelnut shrubs on a privately owned parcel that adjoins the Orleans Ranger District of the Six Rivers National Forest in the Klamath River watershed. The study location is within the 1919 km^2 ancestral territory of the Yurok Tribe and the 2728 km^2 ancestral lands of the Karuk Tribe (Fig. 3A; Waterman 1920, Baumhoff 1963). In Karuk territory, the federal government did not establish a reservation, leaving merely 3.83 km^2 of Karuk trust lands in their ancestral territory, with the remainder largely under the jurisdiction of the Klamath and Six Rivers National Forests and scattered private homesteads (Fig. 3A; Davies and Frank, 1992; Norgaard, 2014; US Census Bureau, 2017). As a result, Karuk Tribal members and management agencies must navigate the USDA Forest Service claims on their ancestral territory and have limited options to expand their land base through the acquisition of private land holdings. In Yurok territory, multiple overlapping jurisdictions occur including Redwood National Park (192 km^2, Underwood et al., 2003) and Six Rivers National Forest (577 km^2) outside of the reservation established by the federal government. The reservation is located along a one mile buffer from the Klamath River's estuary to ~80 km upriver (~225 km^2; Huntsinger and Diekmann 2010). However, 106 km^2 (47%) of the reservation is under private timber company ownership (Yurok GIS Program 2015). Consequently, the Yurok Tribe must either coordinate or interact with multiple actors within their ancestral territory, but they presently have greater options for acquiring private properties than the Karuk Tribe.

Douglas-fir (*Pseudotsuga menziesii*) and mixed hardwoods (e.g., *Arbutus menziesii*, *Quercus kelloggii*, *Notholithocarpus densiflorus*, *Acer macrophyllum* and *Umbellularia californica*) comprise the forest overstory at the study site. In California, hazelnut is an understory, multi-stemmed shrub (<6 m ht in this study region) that typically occurs below 2,100 m above sea level on mesic sites with well-drained soils (Fryer 2007). Relatively low-intensity fires that historically scarred canopy trees every 10 – 17 years (Wills and Stuart 1994; Taylor and Skinner 1998; Skinner et al. 2006; Crawford et al. 2015) often 'top-kill' understory hazelnut stems, which is when above-ground plant tissues are killed, while below-ground plant tissues remain alive (Anderson 1999).

Fire proxy treatments and prescribed burning of hazelnut shrubs

We replicated fire proxy treatments used by Karuk and Yurok Tribal members to mimic prescribed fires that could be implemented by forest managers at fuel reduction sites with hazelnut shrubs. These fire proxy treatments were: A) cutting all stems in each shrub to ground level (<5 cm) as a means to stimulate coppicing, and to mimic mechanical understory clearing and piling for fuel reduction; B) piling surface fuels (primarily 1-hr, some 10-hr fuels, and adjacent surface litter consisting of needles/leaves) between hazelnut stems to form a small pile (<25 cm height) that was subsequently burned; and, C) applying a propane torch flame near ground level to hazelnut shrub stems until stems blistered indicating stem mortality (Fig. 5). The prescribed fire treatment, referred to here as a 'broadcast' fire treatment, was allowed to spread across multiple hazelnut shrubs (Fig. 5D), while all other fire treatments were constrained to individually targeted shrubs.

We employed a randomized block design to establish 27 stratified blocks (block = 16 m^2) that included each treatment, except for the broadcast fire treatment (Fig. 7A). Blocks were selected if they contained at least four hazelnut shrubs spaced > 1 - 2 m apart with similar dimensions (e.g., shrub height, total stems, and stem diameter; Fig. 7B). Subsequently, total stems and the potential 'usable' basketry stems were counted within each hazelnut shrub and shrub height was measured over a 15 day period preceding the implementation of treatments on May 14, 2008. Based on basketweaver selection criteria, basketry stems were defined as straight stems > 10 cm long without branching. Shrub height as well as the slope, aspect, and canopy cover were recorded within each block. Slope was measured using a Suunto PM-5/360 PC Clinometer, aspect was recorded using a compass, and canopy cover was measured four times with a spherical concave densiometer at each cardinal direction above each shrub, to obtain a mean value (%) for each individual (Lemmon 1956; Fiala et al. 2006). Aspects between 135° and 225° were classed as southern (n=56) and aspects between 45° and 134° were classed as eastern (n=49). Canopy cover ≤ 50% (n = 12) was categorized as 'low', cover ≥ 51% and < 70% as 'medium' (n = 63), and ≥ 70% as 'high' (n = 30). After our pre-treatment surveys, we randomly treated three of the shrubs within each block with a fire proxy and one shrub was designated as an untreated control (Fig. 7B).

Historically in Karuk and Yurok territory, cultural burns primarily were applied in the fall months (Harrington 1932; O'Neale 1932; Thompson 1991; Stewart 2002) with some occurring in spring months (Lake 2007; Halpern 2016). Given the unpredictable availability of broadcast burn conditions, the experimental and sampling design was conservative with all three fire proxy treatments and controls replicated as we were unsure whether broadcast burns could be included in this study. Fortunately, suitable prescribed fire conditions occurred on October 28, 2008 and a broadcast burn was applied to ~5 ha affecting 12 of the 27 treatment blocks (Fig. 7A). Fire lines were established to preserve ~50% of the previously treated blocks in order to compare the intact fire proxy treatments to the broadcast burn treatment (Fig. 7A). A backing fire with strip ignitions (3 – 5 m apart) was set with drip torches, and the fire burned from 14:20 to 16:30 hours (Fig. 5D). Temperature ranged from 69.5° F to 75.0° F, relative humidity spanned 39.5% - 48.0% and the Yurok RAWS station (9 km from site) recorded fuel moistures between 7.4% and 12.3%. The fifteen blocks with three fire proxy treatments and a control that were not affected by the prescribed broadcast fire were then re-surveyed the following year (May 2009) when stems were suitable for harvest (n = 60 shrubs). Only one of the fifteen pile burned shrubs died. After a full growing season (18 months post-burn; April 2010), we re-surveyed 45 out of 48 shrubs in the 12 broadcast burned blocks as three tagged shrubs could not be re-located. Post-treatment measurements included the density of basketry stems, total live stems, and the presence of deer browse within each shrub.

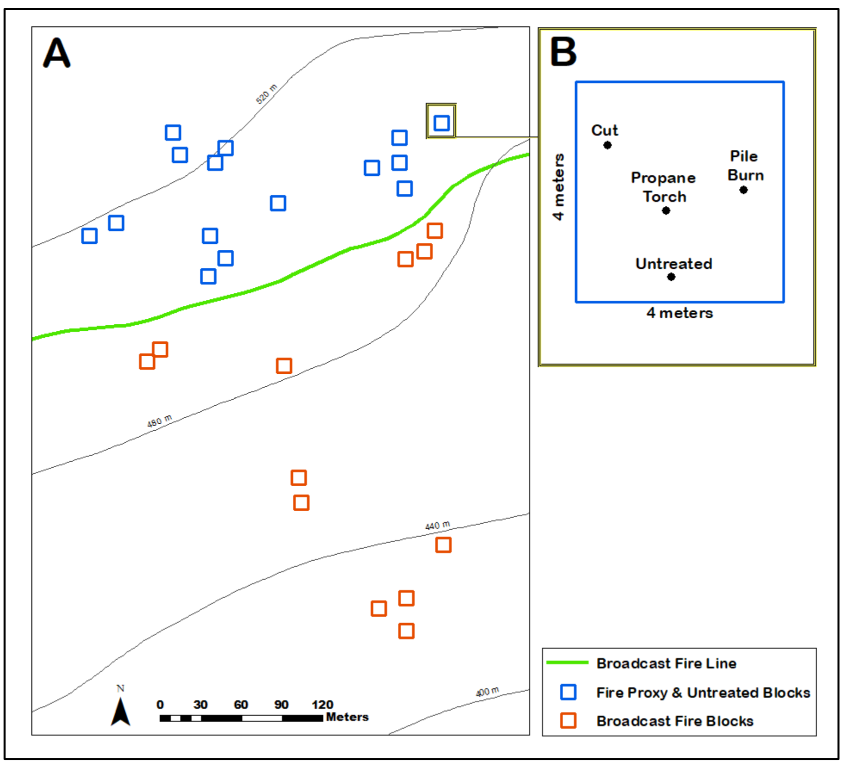

Figure 7. Study Site with Treatment Block Design. (A) Spatial distribution of treatment blocks. The broadcast fire line divides the 15 fire proxy and untreated blocks from the 12 broadcast fire treated blocks. Contour lines depict the elevation and aspect at the site. **(B)** Schematic block (16 m^2) with four hazelnut shrubs (filled circles) that received fire proxy treatments.

Hazelnut stem measurements

On May 8, 2009, we harvested basketry stems (*n*=604) produced from 50 shrubs in the cut (*n*=233), propane (*n*=205), pile burn (*n*=148), and control (*n*=18) treatments. Stems were cut < 5 cm from the ground, labeled, and then bark was removed to prepare the stem for weaving. Stem diameter was measured with a digital caliper and stem length with a meter tape. These stems harvested from the fire proxy treatments were then compared to hazelnut stem collections gathered on May 3, 2008 by two experienced Karuk/Yurok basketweavers (*n*=396 and *n*=73) from an earlier prescribed broadcast burn (October 2006) adjacent to the experimental study site.

Data Analyses

To evaluate the production of post-treatment basketry stems in each shrub among the different treatments, we developed a negative-binomial generalized linear mixed model (GLMM) using the glmmTMB package in R (R Core Team 2014; Magnusson et al. 2017). Block was set as a random effect, and treatment, aspect class, slope, the presence of deer browse, pre-treatment total stems, and canopy cover classes were included as covariate fixed effects. Pre-treatment total stems were also included as a fixed effect to evaluate if shrub size affected the quantity of post-treatment basketry stems. We used Type III Wald Chi Square tests to perform backwards selection to find the model of best fit. To analyze the differences within categorical variables that showed significance in the GLMM, we generated Estimated Marginal Means (EMMs) to address imbalances in the study design (e.g., 45 broadcast shrubs versus 15 pile burned shrubs) using the emmeans package and compared 95% confidence intervals using the Tukey and Dunnett methods (Lenth 2018).

To analyze the length and diameter of stems gathered from the fire proxy treated and control shrubs, we developed two gamma distributed GLMMs using the glmmTMB package. Each shrub was set as a random effect in the model, and treatment, pre-treatment shrub height, aspect class, and canopy cover class were treated as covariate fixed effects. We generated models of best fit using backwards selection with Type III Wald Chi Square tests, and produced EMMs to analyze differences in stem lengths and diameters within categorical variables using the Tukey method. Stem length and diameter distributions from our treatment samples were compared with the collections of two basketweavers using a multiple comparison Wilcoxon Rank Sum test (Kabacoff 2015).

RESULTS

The 86 treated hazelnut shrubs produced a total of 923 basketry stems (10.73 per shrub ± 1.02), whereas the 19 control shrubs produced only 20 basketry quality stems (1.05 per shrub ± 0.45). Within the broadcast burned blocks, six shrubs had died while four shrubs were unburned and were then included in the untreated (control). All hazelnut shrubs that were treated with either pile burning, propane torching, and, or a prescribed broadcast burn increased the production of basketry stems from 7 to 10-fold in comparison with the shrubs in the untreated controls ($p < 0.001$, Table 2, Fig. 8). However, the quantity of basketry stems per shrub produced by the cut treatment (EMM = 6.5, SE = 1.61) was only 4-fold greater than the untreated controls (EMM = 1.54, SE = 0.60, $p = 0.006$, Table 2). The EMM of the cut treatment was reduced significantly when compared with the EMM of the propane treatment (EMM = 15.45, SE = 2.79, $p = 0.025$, Fig. 8). Basketry stems among the propane, pile burn (EMM = 10.98, SE = 2.36), and broadcast (EMM = 11.54, SE = 1.84) treatments did not exhibit significant differences (all = $p > 0.25$, Fig. 8).

Pre-treatment total stems ($p < 0.001$), aspect class ($p < 0.01$), and canopy cover class ($p < 0.05$) imparted significant effects on basketry stem production in hazelnut shrubs (Wald Type III Chi Square test; Table 3). Shrub size (pre-treatment total stems) and basketry stem production exhibited a strong positive relationship ($p < 0.001$, Fig. 9). Shrubs within eastern aspect classes produce 1.73-fold more basketry stems ($n = 49$, EMM = 9.48, SE = 1.18) than those in southern aspect classes ($n = 56$, EMM = 5.47, SE = 1.19, $p < 0.01$). Within the canopy cover classes, the shrubs within the medium canopy cover class ($n = 63$) produced a 5.08 EMM (SE = 0.86) of basketry stems, whereas shrubs within the high canopy cover class ($n = 30$) produced 1.84-fold greater basketry stems (9.36 EMM, SE = 1.75, $p = 0.03$) than the medium canopy cover class. Shrubs within the low canopy class ($n = 12$) had a 7.87 EMM (SE = 2.00) and did not differ significantly from shrubs in the high ($p = 0.83$) or medium canopy cover classes ($p = 0.27$). Within the initial negative-binomial GLMM, deer browse and slope did not impart significant effects on basketry stem production ($p > 0.05$).

Basketry stem lengths gathered from the treated and control shrubs ranged from 11.00 – 118.60 cm ($\mu = 43.24$, SE = 0.83) and stem diameters ranged from 0.53 – 5.76 mm ($\mu = 2.30$, SE = 0.04, Fig. 10). Basketweaver1 gathered stem lengths ranging 14.10 to 81.20 cm ($\mu = 38.97$, SE = 0.58), and Basketweaver2 gathered stem lengths ranging 27.80 to 73.40 cm ($\mu = 47.76$, SE = 1.29, Fig. 8B). From basketweavers' sourced materials, stem diameter ranged from 0.96 – 4.11

mm (μ = 2.13, SE = 0.03) and 1.64 – 4.45 cm (μ = 2.89, SE = 0.07), respectively (Fig. 10A). The distribution of basketry stem lengths and stem diameters gathered by Basketweaver2 were greater than those gathered by Basketweaver1 as well as those stems harvested from the fire proxy treatment blocks and broadcast burn (Wilcoxon rank sum; $p < 0.001$, Fig. 10). However, similar stem length and diameter distributions were recorded from stems harvested in the fire proxy treatment blocks and broadcast burn as well as those gathered by Basketweaver1 ($p > 0.05$).

Results from the gamma GLMMs showed that pre-treatment shrub heights and aspect classes had a significant effect on basketry stem lengths and diameters from treated and control shrubs. A strong positive relationship was detected between pre-treatment shrub height and post-treatment stem lengths and diameters ($p < 0.001$). Shrubs within the southern aspect class produced both shorter length (EMM = 34.4 cm, SE = 1.62) and smaller diameter (EMM = 1.87 mm, SE = 0.08) stems post-treatment than eastern aspects (diameter EMM = 2.52 mm, SE = 0.15; length EMM = 47.6 cm, SE = 2.79, $p < 0.001$). Between the treated and control shrubs, basketry stem length did not differ significantly. However, the stem diameters harvested from the pile burn (EMM = 2.00 mm, SE = 0.12) and cut (EMM = 2.49 mm, SE = 0.127) treatments were significantly different ($p = 0.02$). Propane treated stem diameters (EMM = 2.14, SE = 0.11) were nonsignificant in the model ($p = 0.15$). No discernable effects of canopy cover classes on stem diameter or length were detected.

Table 2. Effects of the fire proxy and broadcast burn treatments (e.g., cut, pile burn, propane, broadcast) on hazelnut basketry stem production compared with the untreated control. Estimated Marginal Mean (EMM) is back-transformed from the log scale and averaged over the values of aspect and canopy classes. The contrast to control ratio is the treatment EMM to untreated control EMM (1.54, SE = 0.60). The confidence intervals, *t*-statistic and *p*-values were generated using the Dunnett method.

Treatment	n	EMM	Contrast to control ratio	Contrast SE	CI	*t* ratio	*p* value
Cut	15	6.45	4.19	1.87	1.38 – 12.7	3.22	0.0066
Pile Burn	15	10.98	7.13	3.05	2.46 – 20.7	4.59	0.0001
Propane	15	15.45	10.05	4.16	3.57 – 28.2	5.57	<0.0001
Broadcast	41	11.54	7.50	3.07	2.70 – 20.9	4.92	<0.0001

Table 3. Variables Affecting Basketry Stems Within Study Blocks. Results of a Wald Type III Chi Square test on the significance of the treatments (control, cut, pile burn, propane, broadcast), pre-treatment total stems, aspect class, and canopy class on basketry stems generated from a negative-binomial generalized linear mixed model (GLMM). Aspects between 135° and 225° were classed as southern (n = 56) and aspects between 45° and 134° were classed as eastern (n = 49). Canopy cover ≤ 50% (n = 12) was categorized as 'low', cover ≥ 51% and < 70% as 'medium' (n = 63), and ≥ 70% as 'high' (n = 30). Two additional biophysical variables (deer browse, slope) did not exhibit strong effects on basketry stems (p > 0.05) and were removed from the model. Hazelnut shrub blocks (n = 27; 16 m^2) are set as random effects.

Fixed effect	χ^2	Df	$p(>\|\chi^2\|)$
Treatment	35.38	4	<0.001
Pre-treatment total stems	23.11	1	<0.001
Aspect class	6.99	1	0.008
Canopy class	7.14	2	0.028

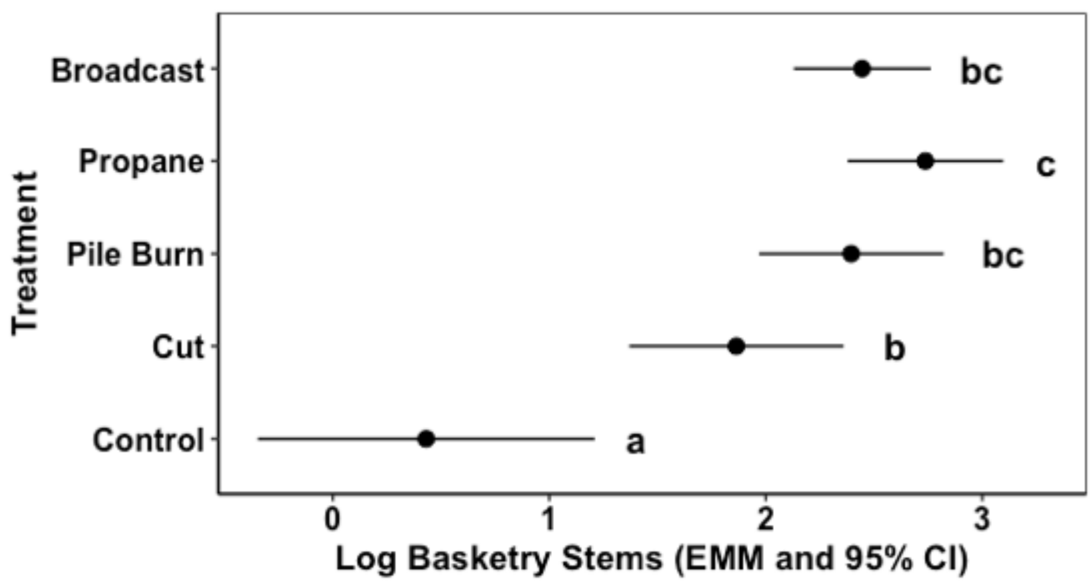

Figure 8. Fire Proxy Treatment, Broadcast Burn, and Untreated Control Effects on Hazelnut Basketry Stem Production. Estimated marginal means (EMM) of basketry stems with 95% confidence intervals (log scale) within the control and four fire proxy treatments. Letters indicate significant differences between treatments (p < 0.05).

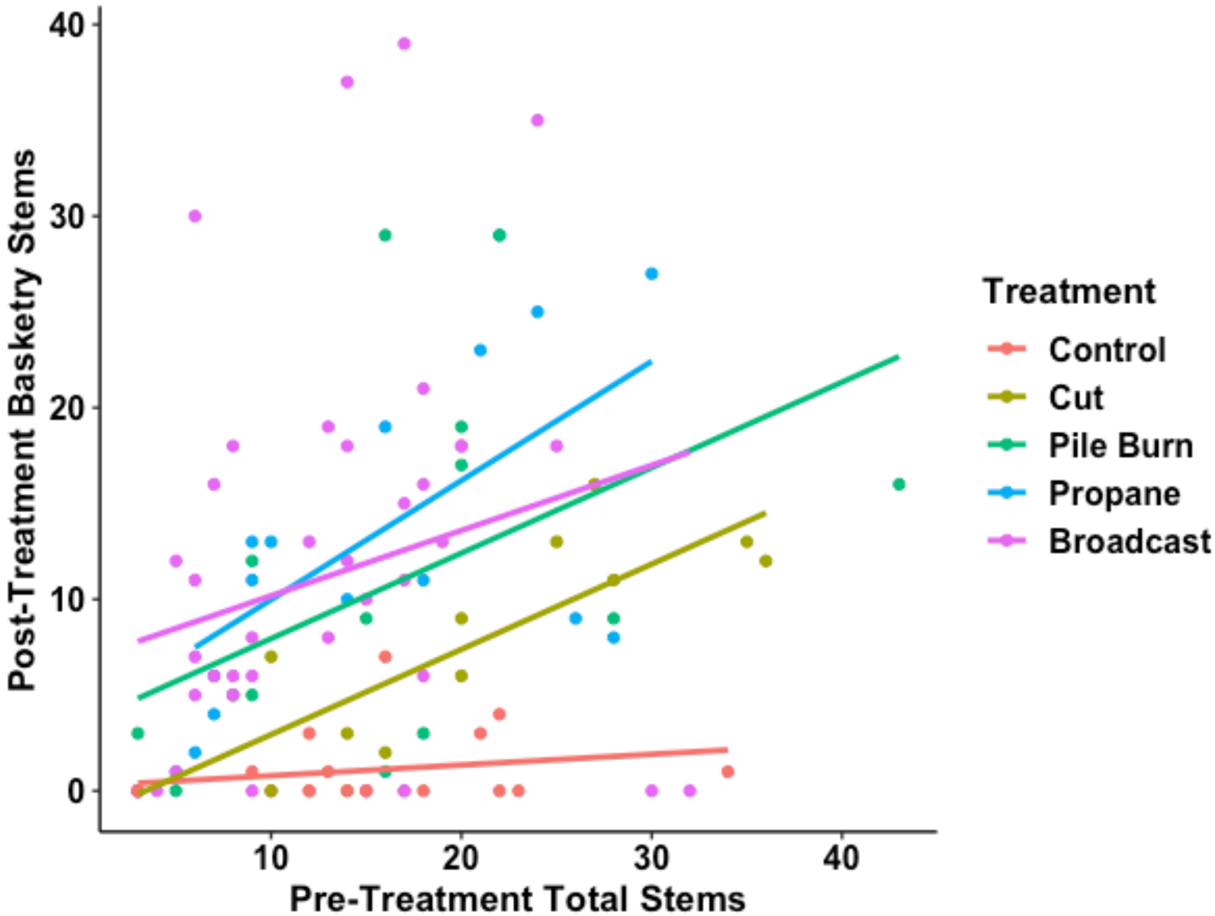

Figure 9. Pre-treatment Total Stems (shrub size) Positively Affect Post-treatment Basketry Stem Production. Pre-treatment total stems and post-treatment basketry stems are plotted by treatment with lines of best fit determined by ordinary least squares regression.

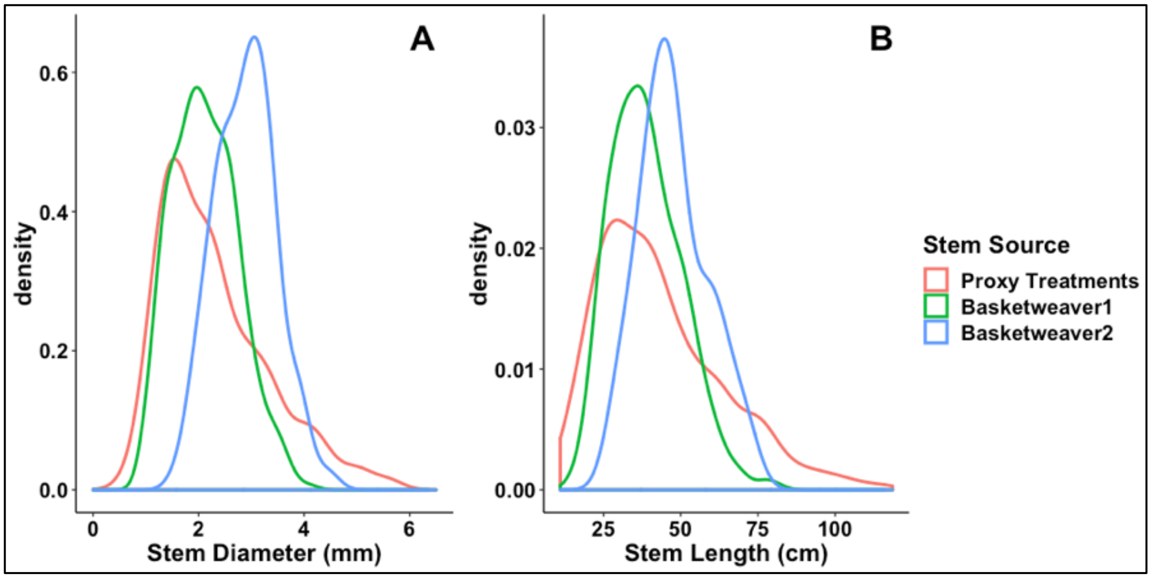

Figure 10. Treatment Effects on Hazelnut Basketry Stem Size Distributions Compared with Basketweavers' Harvests. Samples were gathered from 46 treated and 4 untreated shrubs (*n*=604), and collected by Basketweaver1 (*n*=396) and Basketweaver2 (*n*=73). Fire proxy treatment and control stem size distributions did not differ significantly from the distributions gathered by Basketweaver1 (Wilcoxon Rank Sum; $p = 0.5$). However, the stem size distributions from Basketweaver2 differed significantly from all treatments and Basketweaver1, but based on a relatively small sample size (Wilcoxon Rank Sum; $p < 0.001$). A) Stem diameter (mm) and B) stem length (cm). Distributions shown as kernel density plots.

DISCUSSION

The application of three fire proxy treatments and a prescribed broadcast fire treatment indicate that all treatments generated 4 – 10-fold increases in basketry quality hazelnut stems when compared with the untreated hazelnut shrubs. Untreated (control) hazelnut shrubs contained only 1.54 ±0.60 basketry stems per shrub, and thus, are deemed marginal, or too limited in value for California Indian basketweavers (Anderson 1999). Thus, broadcast fires or substitute treatments are required to generate basketry quality stems.

Basketweavers prefer cultural burns to treat hazelnut shrubs for basketry because they efficiently top-kill many hazelnut shrubs relatively rapidly, and thus, create improved gathering rates for basketweavers. Cultural burns also may have positive effects upon additional ecocultural species and may reduce understory fuels. Although our broadcast burn treatment was effective at producing basketry stems, ~15% of broadcast burned hazelnut shrubs died, and thus reduced the basketry stems expected from this treatment. While we did not assess pre-burn surface fuel loads before ignition, the landowner had not previously conducted fire treatments in the broadcast burn area, suggesting that surface fuel loads may have been relatively higher than in a historically, and thus, more frequently burned forest. Decades of fire exclusion increase surface fuel loadings that generate increased fire intensities and shrub mortality during prescribed burns (Kauffman and Martin 1990; Thaxton and Platt 2006). In the absence of broadcast burns, pile burning and propane torch burning treatments also are effective methods to top-kill hazelnut shrubs. When creating piles within hazelnut shrubs practitioners may avoid piles with high fuel loads and inordinate fire residence time to prevent shrub mortality resulting from excessive direct heat (Siefkin et al. 2002). Only ~7% of monitored shrubs died from our surface fuel piles when they were composed of 1-hr, 10-hr, and surface litter fuels with height limited to < 25 cm, but establishing fuel load and fire residence time limits or guidelines through additional research would be useful especially when expanding these applications over large areas.

In contrast to our cutting treatment that focused solely of hazelnut stems, mechanical cutting is widely used by agencies and landowners to create shaded fuel breaks (65 – 400 m wide) and is typically paired with the pile burning of cut woody debris (Agee et al. 2000; Rhoades and Fornwalt 2015; Vaillant and Reinhardt 2017). When burned hazelnut shrubs are unavailable or insufficient basketweavers will gather basketry stems opportunistically within these mechanically created fuel breaks if suitable coppiced hazelnut shrubs occur. However, basketweavers report reduced stem strength or pliability from mechanical treatments compared to burn treatments, which is supported by lower wood-to-pith ratios in these stems (Rentz 2003). The lower stem quality and reduced expected stem density from cut treatments considerably reduces basketweavers' preference for this treatment.

The four environmental variables we measured (e.g., slope, deer browse, canopy cover, and aspect) appear to explain some of the variation observed in hazelnut basketry stems production. Deer browse occurred on only five of the 105 hazelnut shrubs measured, and thus, in this particular case deer browse was inconsequential. Yet, deer herbivory typically occurs at the axil tip of new basal shoots. Subsequently, the hazelnut shrub typically produces two or more lateral branches below where the apical bud and leaves were eaten, producing an unsuitable basketry stem. Thus, if deer or other ungulate browsers are abundant (e.g., at sites further from private residences), browse could become a major factor in the reduction of basketry stems.

Hazelnut shrubs in the 'high' canopy cover class produced 1.84-fold more basketry stems than those in the 'medium' canopy cover class. These results support Karuk and Yurok basketweavers' experience and observations. Areas with relatively low canopy cover (i.e., 0 – 20%) and increased light conditions stimulate lateral branching within hazelnut basal resprouts, reducing the potential density of basketry quality stems (Johnson and Marks 1997; Ortiz 1998; Lake 2007). However, the shrubs within the 'low' canopy cover class produced highly variable basketry stems whose EMM was 1.55-fold greater than shrubs in the 'medium' canopy cover class although the EMM did not differ significantly. Only four shrubs in the low canopy cover class had 30% cover, and the remaining eight shrubs in that class were 50% cover, which reflects limitations in both our sampling effort and truncated range of measured canopy cover (30% - 85%) within a 10 ha sampled area. Given that southern aspects in the northern hemisphere are exposed to additional solar radiation than eastern aspects, shrubs with southern exposures (EMM = 5.48) produced significantly fewer basketry stems than those in eastern aspects (EMM = 9.48, Barbour et al., 1987: 341). Overall, additional sampling of shrub responses to treatments across the full aspect range would improve these analyses and our understanding.

Plant branching and architectural responses to sunlight are exceptionally diverse and show phenotypic plasticity (Valladares and Niinemets 2007). In unburned and non-coppiced temperate deciduous understory trees and shrubs, lateral branching can be stimulated by increased light conditions (Pickett and Kempf 1980; Canham 1988; Bonser and Aarssen 1994; Charles-Dominique et al. 2012; Hamelin et al. 2015). California hazelnut appears to change its plant architecture from a sympodial form in full sun to a monopodial form under forest canopies much like the multi-stemmed shrub, *Rhamnus cathartica* (Charles-Dominique et al. 2012). However, more detailed morphological measurements are required to confirm these hazelnut architecture forms.

Aspect class also affected stem length and diameter in the GLMMs analyses. Stems measured from eastern aspects were 1.38-fold longer and 1.35-fold wider compared with those in southern aspects. These results align with basketweaver knowledge that shrubs with full sun exposure produce shorter stems than those under canopy cover. Similarly, the Mediterranean shrub *Arbutus unedo* has been shown to produce taller resprouts post-fire when growing in northern and eastern aspects compared to southern and western aspects (Konstantinidis et al. 2006). However, our observed decrease in viable basketry stems in southern aspects and medium canopy cover should not be misconstrued to suggest that burning should be limited under these site conditions because shrubs under these conditions still produce at least a 5-fold increase in basketry stems as untreated shrubs.

Treatments did not have a detected effect on stem length. However, the cut treatment produced 1.25-fold greater stem diameters than the pile burn treatment. Cut treatments may not induce as much physiological stress or loss of stored energy as compared with burning treatments, and thus, the shrub may have sufficient resources to produce more robust stems with greater diameter. Several studies have found that high severity fires reduce shrub resprouting vigor and biomass compared with low severity fires and cutting treatments (Lloret and López-Soria 1993; Keeley 2006; Clarke et al. 2013; Fernández et al. 2013a), however other studies have found that severity does not correlate with resprout vigor in other shrub species (Drewa et al. 2002; Keeley et al. 2008; Fernández et al. 2013b).

Stem diameter and stem length distributions harvested from the treated and control shrubs (*n* = 604), were similar to those harvested from a broadcast burn by Basketweaver1 (*n* = 396). Thus, our fire proxy and broadcast burn treatments appeared to produce stem qualities that are preferred by basketweavers. However, Basketweaver2 harvested a distinctive set of stems. Admittedly, this stem sample from Basketweaver2 is relatively limited (*n* = 73) when contrasted with our treatments and Basketweaver1. Most importantly, basketweavers reported that some basketry projects may require different sets of stem diameters and lengths. Therefore, basketweavers' aims must be considered when comparing hazelnut stem harvesting activities.

Our results demonstrate that expanding the area and frequency of targeted understory fire-based forest treatments on private, public and Tribal lands in the Pacific Northwest and California would generate greater availability and distribution of basketry hazelnut stems that are currently limited in supply and in high demand (Ortiz 1993; Baldy 2013; Long and Lake 2018). Small-scale (≤10 ha) application of these fire proxy treatments appears quite feasible both for private landholders or on public lands that would require minimal permitting as well as limited labor and low material costs. The constraints associated with prescribed and cultural burns, such as the limited burning season and increased liability concerns in close proximity to residences within the Wildland Urban Interface, do not necessarily apply to these fire proxy treatments because they can be conducted when prescribed burning conditions are risky or biophysically not possible (e.g., either elevated or low dead surface fuel moisture). Due to these and other constraints, the USDA Forest Service currently is able to implement understory mechanical fuel reduction treatments across a greater area than broadcast burning to reduce fuels in California and the Pacific Northwest (Vaillant and Reinhardt 2017). Yet, the three fire proxy practices examined here appear to be highly compatible for integration into larger-scale USDA Forest Service, or other fuel treatment programs (≥ 10 ha), and likely would require only minor adjustments to current understory mechanical fuel reduction practices to meet these additional Tribal ecocultural objectives. For example, if the woody debris from these understory mechanical treatments are pile burned, hazelnut burn piles (< 25 cm) or propane torching could be incorporated into this fuel reduction activity, increasing hazelnut stem productivity. Further, hazelnut stems could be included for removal in mechanical understory thinning treatments, if they were initially excluded from the prescription. While Tribal members prefer broadcast burning for ecocultural resource production, they recognize that mechanical understory treatments are necessary to address decades of fire exclusion, and prepare sites for broadcast burning in the near future (USDA Forest Service PSW Region 2018). If areas of high hazelnut shrub densities are either known or identified in consultation with Tribes and basketweavers, and align with fuel reduction objectives, the subsequent production of basketry stems from mechanical treatments would provide additional benefits to the fuel reduction value of this treatment. Given that hazelnut is distributed across 75% of the NWFP area, limited efforts are required to identify these suitable areas (Long et al. 2018b).

Policies that support Tribal consultation within public land agencies offer effective opportunities for increased and effective collaborations and communication in forest management (Donoghue et al. 2010; Bussey et al. 2015; Dockry et al. 2017; Lake et al. 2017). Since this initial experimental study was conducted, prescribed burning and fuel treatments have expanded throughout northwest California, largely as a result of inter-governmental and community partnerships that aim to manage public, Tribal, and private lands (Harling 2015; Yurok Tribe 2015; Long et al. 2018b; USDA Forest Service PSW Region 2018).

Throughout this study, we sought to incorporate Indigenous knowledge and participation with 'western' scientific approaches to support these expanding collaborative efforts among Tribal governments and public land agencies. Fire exclusion policies forced California Indian communities and forest managers to curtail their routine cultural and prescribed burning practices. Despite these policies, Karuk and Yurok basketweavers retained their knowledge, maintained their practices and, most importantly, developed several innovative techniques to replicate fire's effects on hazelnut to produce essential basketry materials. To support their efforts, we quantified their hazelnut fire treatment outcomes with the aim to inform managers of their efficacy and material importance, to facilitate increased forest access, and to reduce bureaucratic processes required for Tribal members who seek to employ these fire proxy treatment methods and broadcast burns. Moreover, we encourage efforts to explore creative applications that aim to incorporate these hazelnut fire proxy practices within government-led understory mechanical fuel thinning and large-pile burning treatments. Through such collaborative processes, basketweavers and Tribes may be able to receive financial and logistical support, and, most importantly, recognition and respect for their priorities and experience in managing hazelnut as well as other critical ecocultural resources.

CHAPTER 4

Burning for Baskets: Enhancing California hazelnut (*Corylus cornuta* var. *californica*) densities and revitalizing Karuk and Yurok Indian culture in northwest California

ABSTRACT

The Karuk and Yurok Tribes in northwest California are revitalizing the practice of cultural burning, or prescribed burns for ecocultural keystone species. These cultural burns are critical for Indigenous livelihoods and culture, and were widespread preceding fire exclusion policies. One of the objectives of these cultural burns is to enhance the production of California hazelnut (*Corylus cornuta* var. *californica*) basketry stems for Karuk and Yurok basketweavers. To evaluate cultural burning as a form of human ecosystem engineering we monitored hazelnut basketry stem production, qualities, and shrub density in 48 (400 m^2) plots within 21 cultural burn sites and 12 adjacent unburned areas. A suite of socio-ecological variables were analyzed including land tenure, burn frequency, burn season, canopy tree basal area (≥10 cm dbh), and aspect. We also observed basketry stem gathering to compare travel distances, gathering rates and basketweaver preferences at sites with different fire histories and land tenure. Hazelnut shrubs one growing season post-burn produced a 13-fold increase in basketry stems compared with shrubs growing ≥3 seasons post-burn ($p < 0.0001$). Basketry stem production and stem length displayed negative relationships with canopy tree basal area ($p < 0.01$) and ungulate browse ($p < 0.0001$). Plots that were burned at high frequency (≥3 times between 1989 and 2019) had 1.86-fold greater hazelnut shrubs than plots burned <3 times ($p < 0.0001$), and were all located in Yurok territory where there is comparatively stronger Indigenous land tenure; 73% of observed gathering trips were to sites burned at high frequency. Basketweavers travelled 3.8-fold greater distances to reach gathering sites burned by wildfires compared with those that were culturally burned ($p < 0.01$). At cultural burn sites, wildfire sites, and fire excluded sites mean gathering rates were 4.9, 1.6, and 0.5 stems/minute/individual, respectively. Karuk and Yurok cultural fire regimes with high burn frequencies promote high densities of ecocultural keystone species, and increase hazelnut basketry stem production, increasing gathering efficiency and lowering costs to support the revitalization of a vital cultural practice. Our findings are evidence of positive human ecosystem engineering, and show that increasing Tribal sovereignty over fire management will produce many socio-ecological benefits.

BACKGROUND

Across many different ecosystems, Indigenous burning has been shown to impart positive effects on human and ungulate foraging returns, habitat diversity, and species abundance, as well as the mitigation of wildfire spread by reducing fuel loads, fire intensities and resulting severities (Gottesfeld 1994; Kepe 2005; Sheuyange et al. 2005; Bilbao et al. 2010; Bliege Bird et al. 2012; Fowler 2012; Sletto and Rodriguez 2013; Welch et al. 2013; Coughlan 2014; Codding et al. 2014; Seijo et al. 2015; Trauernicht et al. 2016). Given the substantial shifts in ecosystem functioning generated by Indigenous burning practices, some have suggested it to be a critical ecosystem engineering process that, in the process of modifying the human niche, supports a unique set of plant and animal species adapted to the pyrodiversity typical of an anthropogenic fire regime (Jones et al. 1994; Bliege Bird et al. 2013; Odling-Smee et al. 2013). Globally, profound changes to Indigenous burning practices following land evictions, colonialism, and fire exclusion laws may have resulted in increased vulnerability to climate change, alternative ecological states and species population crashes (Huntsinger and McCaffrey 1995; Guyette et al. 2002; Bliege Bird et al. 2008; Walters 2015; Liebmann et al. 2016; Taylor et al. 2016; Mistry et al. 2019).

In California, fire is a critical biophysical process (Sugihara et al. 2018), and anthropogenic fires set by California Indians had profound effects on fire regimes preceding colonialism (Skinner et al. 2009; Crawford et al. 2015; Klimaszewski-Patterson and Mensing 2016; Taylor et al. 2016). Preceding colonization by the Spanish in 18th century and 19th century American gold rush, these anthropogenic fires were integral to the culture and economy of California Indians through the way they enhanced subsistence and ceremonial resources (Lightfoot and Parrish 2009; Anderson 2018). 20th century fire exclusion policies to protect timber commodities and structures drastically reduced the relative spread of fire (Stephens et al. 2007; Stephens and Sugihara 2018), dispossessed Indians of their land, and suppressed Indigenous burning and culture (Huntsinger and McCaffrey 1995; Lightfoot and Parrish 2009; Aldern and Goode 2014; Lake et al. 2017; Norgaard 2019).

Federal fire exclusion policies began to shift in 1968 to allow prescribed fire and the managed spread of wildfire on National Park lands, and similar policy shifts were made across all federal land management agencies in the 1990s; however, fire suppression is still dominant across California (Stephens and Sugihara 2018). The inclusion of managed wildfire has increased fire frequencies in some areas, like the Illouette watershed in Yosemite National Park (Boisramé et al. 2017). Yet, in the majority of California's wildlands, the re-introduction of fire is hindered by insufficient resources, environmental regulations, risk aversion, and liability concerns (Quinn-Davidson and Varner 2012; Schultz et al. 2018; Miller et al. 2020).

In northwestern California, Indian Tribes such as the Karuk, Yurok, Hoopa, and Tolowa are leading efforts to re-introduce prescribed burning by forming partnerships with public land and fire agencies as well as non-governmental organizations (Underwood et al. 2003; Levy 2005; Salberg 2005; Long and Lake 2018). Amongst these Tribes, prescribed fires are widely accepted and known colloquially as 'cultural fires' or 'cultural burning'. By living in a fire-prone region for millennia, these Tribes developed a reliance on many fire-enhanced species, developed cultural fire regimes, and became fire-dependent cultures (Lightfoot and Parrish 2009; Anderson 2018; Lake and Christianson 2019). The objectives of these fires are to enhance the abundance and quality of species used for material culture, subsistence foods, and ceremony as well as to reduce understory brush and fuels for reducing fire hazards and to facilitate travel across the landscape (Hunter 1988; Levy 2005; Lake 2013; Aldern and Goode 2014). As Roos et al. (2016) propose, this region has a key characteristic associated with fire-adaptive communities (i.e., communities with capacity to respond to fire-related challenges), which is the "broad recognition by individuals of the benefits of fire-promoted resources and amenities relative to the tradeoffs". Thus, cultural fires are emergent properties and practices of fire-dependent cultures that present an exceptional opportunity to evaluate the socio-ecological processes that increase adaptive capacity to fire, and as examples to society for 'learning to live with fire'.

As North American fire management agencies shift to increase the frequency and scale of prescribed and managed wild fire (North et al. 2012; Ingalsbee 2017), and American Indian Tribes achieve greater influence over fire and land management (Lake et al. 2017; Long and Lake 2018), there will be more opportunities to assess fire effects on 'ecocultural species,' or those species with ecological, spiritual, economic, and cultural values for American Indians (Garibaldi and Turner 2004; Long et al. 2018b). Ecocultural fire-enhanced species continue to be used by American Indians and other communities for basketry materials, foods, and medicines (Ortiz 1993; Anderson 1999; Shebitz 2005; Shebitz and Kimmerer 2005; Griffith et al. 2007; Mathewson 2007; Turner et al. 2011; United States Fish and Wildlife Service 2011; Dobkins et al. 2016; Wynecoop et al. 2019; Sowerwine et al. 2019). Hence, incorporating Indigenous ecocultural objectives into prescribed burning will support cultural and socio-economic revitalization while achieving broader restoration and wildfire hazard reduction goals (Lightfoot and Parrish 2009; Lake et al. 2017; Anderson 2018; Lake and Christianson 2019).

In recent decades one of the major objectives for conducting cultural burns in Karuk and Yurok ancestral territories (Fig. 11) has been to enhance the production of basketry materials for Indigenous basketweavers (Hunter 1988; Senos et al. 2006). California Indians use baskets in all aspects of their culture, such as: child-rearing; food harvesting, processing, and storage; fishing and animal traps; clothing/regalia; and ceremonies (Johnson and Marks 1997; Bibby 2004; Shanks 2006; Mathewson 2007). Furthermore, there is a long history of California Indians selling baskets to friends, acquaintances, and non-native collectors to supplement their income (Cohodas 1997; Smith 2016). But baskets are more than just functional, or a commodity to be sold at craft fairs or placed in a museum, they embody spiritual connections to the ancestors and ancestral beings as told in Karuk and Yurok stories (Kroeber 1978; Kroeber and Gifford 1980; Lang 1994; Smith 2016). Northwest California Indian culture and spirituality is deeply tied to the land and the ancestors, and basketweaving is one of many manifestations of these social and ecological relationships within this fire-dependent culture. The use of baby cradles, for example, is critical to Karuk and Yurok child-rearing and teaching traditions that, according to Karuk leader, Leaf Hillman, fosters a child's ecological observations and a perspective that "human beings [have] a unique potential for affecting the [ecological] system – positively as well as negatively" (Hillman and Salter 1997: 24). The positive ecological effects of cultural burning, as a spiritual responsibility, are reinforced as Karuk and Yurok children's lives become inter-connected with fire-enhanced ecocultural species.

Baskets are also considered to be prayers that offer a conduit to spiritual beings during ceremony (Lang 1991; Buckley 2002; Baldy 2018). They also offer opportunities for basket-makers to communicate in a material, symbolic fashion, creating social relationships with those who observe or use the baskets. The phenomenal skill displayed through basketry represents a dedication and connection to the woven plants and animals incorporated into baskets, as well as to Indigenous spirituality. As such, the weavers of baskets and other regalia are bestowed with prestige and respect that undoubtedly benefits their social standing (Lang 1991; Johnson and Marks 1997; Bliege Bird and Smith 2005; Field 2008). The revitalization of basket-making is driven in part by conscious decisions to actively restore the traditions of their ancestors, despite a century of assimilationist policies that outlawed ceremony, cultural burning, and livelihoods (Nelson 1978; Norton 1979; Huntsinger and McCaffrey 1995). As Karuk author Julian Lang suggests, ceremonies have returned because of Tribal members' determination to "participate in communal displays of regalia" that connect them with "the Spirit Beings" (Field 2008: 92).

One of the most highly valued and coveted species for basketweaving are the young stems of California hazelnut (*Corylus cornuta* var. *californica*; Ortiz, 1998, 1993; Smith, 2016), a multi-stemmed, deciduous shrub which is an excellent example of an ecocultural keystone species (Garibaldi and Turner 2004; Armstrong et al. 2018). Hazelnut stems continue to be particularly important in weaving baby baskets (cradles), which are composed of ~300 hazelnut stems and currently are sold for ~$800. As Maggie Peters, a Yurok basketweaver told me, "These baskets are in high demand by northwest California Indian families who want their children to begin their lives in a cultural way" (M. Peters, pers. com., 2018).

Cultural burns manipulate the post-fire response of California hazelnut, stimulating it to re-sprout from underground buds (Fryer 2007; Clarke et al. 2013), and produce straight shoots whose stems are suitable for use in basketweaving. Historically, burning would occur predominantly in the summer and fall months, and sometimes in the spring (Lake 2007). Hazelnut stem regrowth would be harvested in the following spring (April/May) after one full growing season (spring burn 10-12 months, fall burn 18 – 21 months post-burn; Lake, 2007; O'Neale, 1932; Thompson, 1991). However, fire exclusion has created a scarcity of basketry stems for basketweavers (Heffner 1984; Ortiz 1993; Smith 2016).

In the context of assimilation and land dispossession policies, it was difficult for basketweavers to access materials, and as a result the practice of basketweaving suffered (Heffner 1984; Peters and Ortiz 2010; Smith 2016). Consequently, the connection with ecocultural species and the land was also compromised (Willette et al. 2016; Norgaard 2019). In 2016, one basketweaving class in Weitchpec had insufficient stems for teaching, and teachers had to purchase materials at a crafts store (T. Marks-Block, pers. obs., 2016) In the absence of sufficient cultural burning or wildfires, basketweavers sometimes substitute stems from the less preferred sandbar willow (*Salix exigua*). These stems are less pliable and strong, and also are increasingly rare due to fewer river floods that initiate straight basal resprouting (O'Neale 1932; Lake 2007).

Under fire exclusion policies that made cultural burns illegal, some basketweavers developed alternative techniques to stimulate the growth of hazelnut basketry stems, such as cutting (coppicing), propane torch burning, and pile burning (Heffner 1984; Hunter 1988; Ortiz 1998; Marks-Block et al. 2019). Other basketweavers have been able to maintain burning for basketry materials in small areas throughout the fire exclusion era (Bower 1978; Heffner 1984; Hunter 1988; Ortiz 1998). With the expansion of cultural burning in the region, the opportunity arose to evaluate broadcast burning across a more extensive geography; in areas that had maintained relatively short burning intervals in recent decades (i.e., every 3 – 10 years), and at sites that only recently had been burned after years of exclusion. These differences in burn frequency allowed me to compare the effect of repeated cultural burning on hazelnut basketry stem production and shrub density.

Institutional support for cultural burning in northwest California initiated in 2013 through the prescribed fire TRaining EXchanges (TREX), and in 2014 the Six Rivers National Forest began the Roots and Shoots project on the Lower Trinity/Orleans/Ukonom Ranger Districts. TREX is a program under the 'Promoting Ecosystem Resilience and Fire Adapted Communities Together' agreement between the USDA Forest Service and The Nature Conservancy, that invests in cooperative and collaborative burning across the United States (Butler and Goldstein 2010; Harling 2015; Spencer et al. 2015). In Karuk and Yurok territory, TREX provides financial and logistical support to develop burn plans, process permits, and mobilize fire personnel and equipment for burning, as well as support inter-governmental, inter-agency, and civil society partnerships. The Roots and Shoots project is a Six Rivers National Forest effort developed by the USDA Forest service and basketweavers to burn 176 acres within 25 forest areas containing ecocultural resources identified by Tribal members (Colegrove 2014). Formerly, circa 2004-2007, cultural burns requested by and lead by Karuk/Yurok basketweavers conducted on private property, with assistance from the Orleans-Somes Bar Fire Safe Council also provided opportunities for access to and harvesting of hazelnut shoots (McLaughlin and Glaze 2008; Marks-Block et al. 2019). Among other factors, these initiatives specifically targeted sites with hazelnut to increase basketry stem production.

These initiatives have allowed us to evaluate the effects of cultural fires on hazelnut basketry production. Our first question is whether burning is a form of ecosystem engineering that has positive feedbacks on ecological and cultural processes. If so, we should see that cultural burning increases basketry stem productivity, hazelnut shrub density, or reduces the cost (in search, collecting and travel time) of harvesting suitable stems. Basketweaver ecological knowledge and previous experimental studies (O'Neale 1932; Ortiz 1998; Anderson 1999; Lake 2007; Marks-Block et al. 2019) led us to predict that basketry stem production and quality are primarily affected by time since fire and shrub size (i.e., stem densities), and that burn characteristics (e.g., season, severity, and frequency) and site characteristics (e.g., canopy closure/solar access, aspect, forest stand structure, and deer browse) are other important factors.

Secondly, we ask whether the presence of cultural burning has an effect on species assemblages, such that in the absence of such perturbation, plant communities have shifted to an alternative stable state (Beisner et al. 2003). We hypothesize that repeated, short interval cultural burning acts as a beneficial, culturally desired perturbation in hazelnut groves, and that cultural burning maintains high densities of shrubs and other forest stand characteristics (e.g., relatively low canopy basal area). Following this, if burning is inconsistent or absent, then hazelnut densities will be relatively lower and produce fewer basketry stems post-burn.

We also ask how fire and resource governance in pre-colonial and contemporary contexts effects cultural fire geography, basketry stem availability, and gathering practices. We examine how centralization in governance structures (Larson and Soto 2008) as well as differences in land tenure (Huntsinger and Diekmann 2010; Norgaard 2014) affect fire-enhanced resource use in Karuk and Yurok territory. We make these comparisons based upon the gathering rates of hazelnut basketry stems within different fire regimes and land tenure circumstances. Foraging theory and human behavioral ecology suggest that resource acquisition decisions are informed by micro-economic costs and tradeoffs (Stephens and Krebs 1986; Winterhalder and Smith 2000). As such, we predicted that harvest site selection would be mediated by cultural fire history, hazelnut shrub densities, site productivity, and travel distance to sites, and that differences in Karuk and Yurok land tenure and resource access would influence these variables.

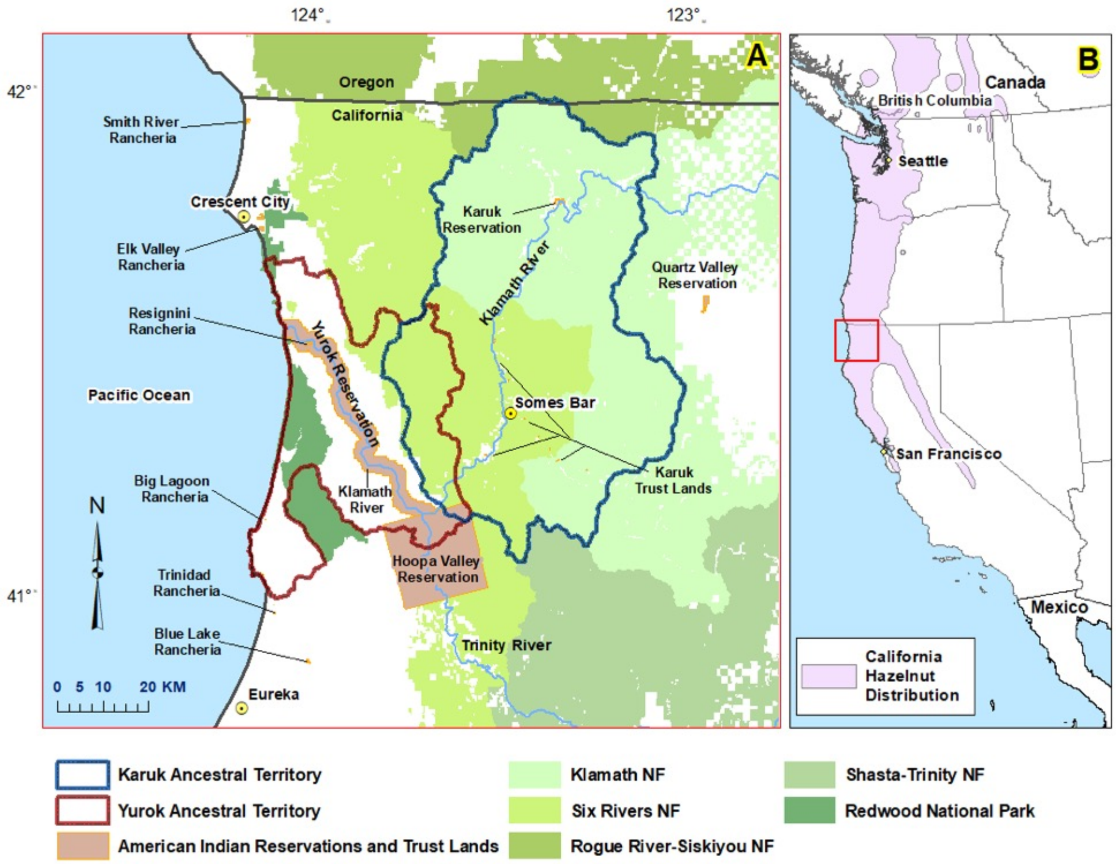

Figure 11. (A) Study Region with Federal Jurisdictional Boundaries and Karuk and Yurok Territories. Ancestral territory boundaries, provided by the Karuk and Yurok Tribes, represent reconstructions, but currently are not fixed or rigid boundaries. Ancestral lands of other Northwest California Tribes (e.g., Tolowa, Wiyot, Hupa, Shasta) are not included here, but note that their ancestral lands may partially overlap with the boundaries rendered here (Baumhoff, 1963). **(B) Western Region of the United States of America, including California hazelnut (*Corylus cornuta* var. *californica*) distribution derived from the *Atlas of US Trees* (Little Jr, 1971).** The study region is depicted by the red box.

METHODS

Study area

The study area consists of burned and adjacent unburned areas within the 1919 km^2 ancestral territory of the Yurok Tribe and the 2728 km^2 ancestral lands of the Karuk Tribe (Fig. 11A; Waterman, 1920, Baumhoff, 1963). In the late Holocene, and preceding colonialism, Karuk and Yurok people relied on acorns, deer, and salmon as primary foods (Tushingham 2009; Norgaard 2019). Settlements historically were concentrated along the

Klamath River and the Pacific coast (Waterman 1920; Kroeber 1936; Bright 1957), and hunting and gathering grounds for critical ecocultural resources were owned and tended by families or individuals (Waterman 1920; Bettinger 2015). Today, the Yurok and Karuk Tribes comprise ~6,000 to ~7,000 members, and are two of the most populous of 109 Tribes currently federally recognized in California (United States Census Bureau 2010b). In Karuk territory, the federal government did not establish a reservation, leaving merely 3.83 km^2 of Karuk trust lands in their ancestral territory, with the remainder largely under the jurisdiction of the USDA Forest Service (Klamath and Six Rivers National Forests) and scattered private homesteads (Fig. 11A; Davies and Frank, 1992, Norgaard, 2014, US Census Bureau, 2017). As a result, Karuk Tribal members and management agencies must navigate USDA Forest Service claims on their ancestral territory and have limited options to expand their land base through the acquisition of private land holdings.

In Yurok territory, multiple overlapping jurisdictions occur including Redwood National Park (192 km^2, Underwood et al., 2003) and Six Rivers National Forest (577 km^2) outside of the reservation established by the federal government. The reservation is located along a mile-long buffer following the Klamath River from its estuary to ~80 km upriver near the confluence of the Klamath-Trinity Rivers (~225 km^2; Huntsinger and Diekmann, 2010). However, 106 km^2 (47%) of the reservation is under private timber company ownership (Yurok GIS Program, 2015). Consequently, the Yurok Tribe must either coordinate or interact with multiple actors within their ancestral territory, but they presently have greater options for acquiring private properties than the Karuk Tribe (Manning and Reed 2019).

The Hoopa Valley reservation was formed within the ancestral territory of the Hupa, Yurok, and Karuk Tribes (Figure 11A) by the federal government in 1874 (Nelson 1978). Although I did not formally collaborate with the Hoopa Valley Tribe that governs the reservation, I formed relationships with and observed many Hupa Tribal members who live or spend time in Karuk and Yurok territories, and Karuk and Yurok Tribal members who live in Hoopa Valley. Tribal members throughout this region are extensively intermarried, and have been from time immemorial (Waterman 1920; Gould 1966; Thompson 1991).

At least five formal basketweaving classes occur weekly in ancestral Hupa, Karuk, and Yurok territories, and informal intergenerational teaching is active within many families. The Cultural Fire Management Council (CFMC) organizes cultural burns in Yurok territory, and all members are either basketweavers, or have basketweavers in their families. When deciding and planning burn locations with limited resources, the presence of hazelnut groves increases the ranking of a potential CFMC burn site. The Hoopa Valley Fire Department also conducts burns for hazelnut stems (Salberg 2005), and the Karuk Tribe works with the Forest Service, the Orleans/Somes Bar Fire Safe Council and private landowners to burn hazelnut groves (Senos et al. 2006; Long and Lake 2018).

Hazelnut basketry stem measurements

From January 2015 to March 2019, I established and monitored 48 plots (400 m^2) in relatively high-density hazelnut groves (≥10 shrubs) within 21 cultural and prescribed burn sites and 12 adjacent unburned areas. Due to the unpredictability of cultural burns, plots were established when I learned of potential burn locations, or after an area was burned. Plots were >2 m from roads and fire control lines and were established after identifying easily accessible hazelnut groves from burn area perimeters or game trails. Multiple plots (2 – 5) were placed within burn areas that contained numerous hazelnut groves to evaluate the effects of environmental heterogeneity on basketry stem productivity within those locations.

Within each plot, I recorded hazelnut shrub density and then ten hazelnut shrubs were randomly selected and tagged. Due to the vegetative, multi-stemmed growth of hazelnut shrubs, individual shrubs selected were >15cm apart. Based upon interviews and observations with basketweavers, suitable quality basketry stems were defined as straight and unbranched stems >10 cm in length. Both total stems and basketry quality stems were measured in the dormant season (October – April). Stems that had been visibly cut and gathered by a basketweaver were counted as a basketry stem. Pre-burn total stems were counted either from previous surveys of the shrub, or from standing dead stems (Keeley 2006). I also recorded growing seasons since the shrubs were burned, and grouped shrub measurements into three temporal classes based on a May – September growing season each year: a) one growing season post-burn (5 – 20 months, n = 302); b) two growing seasons post-burn (21 – 30 months, n = 144); and, c) ≥3 growing seasons post-burn (>31 months, n = 507). Given that basketweavers prefer to gather in areas burned after only a single growing season, typically in April-May (10 – 20 months post-burn), additional data from shrubs within this single post-burn temporal class were recorded. These data included the proportion of stems browsed by deer, elk, and other ungulates for each shrub. Because basketweavers select basketry stems based both on their diameters and lengths, the length of the longest basketry stem was recorded in each shrub as well as the largest and smallest basketry stem diameters that were then averaged.

At all plots, site aspect was measured with a compass and classed as: east (67.5° - 112.5°); southeast (112.5° - 157.5°); south (157.5° - 202.5°); southwest (202.5° – 247.5°); and, west (247.5° - 292.5°). Slope and elevation were measured using a Garmin etrex 30 GPS. Canopy closure measurements were taken facing inward at the four corners of each plot using a spherical densiometer, and then averaged (Lemmon 1956; Fiala et al. 2006). Basal area of each plot was determined by measuring all trees >10 cm dbh with the dominant overstory tree species designated by proportional basal area: *Quercus kellioggi* [Black oak], *Arbutus menziesii* [Pacific madrone], *Umbellaria californica* [Bay laurel] *Pseudotsuga menziesii* [Douglas-fir], and *Pinus ponderosa* [Ponderosa pine], and subsequently classified as conifer or broad-leaf hardwood. Burn char height on trees (>10 dbh) was recorded to the nearest 0.5 m, along with the burn season grouped by winter (Day 355 ± 1) and summer (Day 172 ± 1) solstices, and fall (Day 266 ± 1) and spring (Day 79 ± 1) equinoxes of the burn year. Burn frequency (1989 – 2019) within each plot was ascertained through conversations with landowners, fire managers, and by examining the California Department of Forestry and Fire Protection's prescribed fire GIS database (https://frap.fire.ca.gov/mapping/gis-data/). The frequency was converted into a dichotomous variable: <3 burns or ≥3 burns. Precipitation (cm) was recorded and compiled for a 12-month period beginning in August of the year preceding the survey from either the closest Remote Automated Weather Station (RAWS) to the plot (Yurok, CA; Slate Creek, CA; Somes Bar, CA; Dutch-Indy, CA, Slater Butte, CA, https://raws.dri.edu/ncaF.html), or a privately owned weather station in Forks of Salmon, CA.

Hazelnut stem gathering observations and models

From 2015-2019, I developed working collaborative relationships with basketweavers and hazelnut stem gatherers by attending cultural fire planning meetings (*n* = 13), basketweaving classes (*n* = 15), and by discussing our research interests at Karuk and Yurok Tribe governmental meetings. Through these collaborative exchanges, I conducted in-depth semi-structured interviews (30-60 minutes), attended hazelnut stem gathering trips, and requested and collected gathering diaries from basketweavers to evaluate where and why basketweavers select hazelnut stem gathering areas. I collected six gathering diaries from three basketweavers, and conducted 13 in-depth semi-structured interviews (30 – 60 minutes per interview) with Karuk and Yurok resource users and spoke with seven fire managers about fire-enhanced resource use and cultural burning that included questions on hazelnut burning, hazelnut stem and nut gathering, basketweaving, and the type of property ownership at burn sites. Interviewees were identified and recommended by Karuk staff in the Department of Natural Resources and Yurok leaders on the Tribe's culture committee. The Karuk and Yurok Tribal councils and the Stanford University IRB approved these methods, and individuals provided consent to record gathering practices and statements surrounding hazelnut stem gathering.

During hazelnut stem gathering season (April/May 2015 – April/May 2019), I attended seventeen hazelnut stem gathering trips, wherein I observed individuals gathering hazelnut stems and asked them semi-structured and open-ended questions regarding basketry stem quality, basketweaver gathering site and stem preferences, and the availability and accessibility of hazelnut basketry stems. During these trips, the sum of an individual's harvested stems and their time spent in a hazelnut grove were recorded to produce gathering rates (n = 55). Distances to hazelnut stem gathering areas were recorded from these trips and from basketweaver reports, and were converted to a standard 80 km/hour rate, chosen conservatively due to curvy mountainous roads with a speed limit of 55 mph (88 km/hour). Alongside these distances, the gathering site's fire history was also recorded and then classified as a cultural fire site (n = 41), wildfire site (n = 11), or a fire excluded site (n = 1). I also recorded the ownership (USDA Forest Service, Private, Tribe) and ancestral territory (Karuk, Yurok, Hupa) of the gathering site, and categorized the site quality as relatively 'good' or 'poor' based on basketweaver post-harvest evaluations. From these data, I generated simulations of hazelnut stem foraging that included searching and gathering rates within cultural fire sites, wildfire sites, and unburned sites. We modeled foraging gains as logistic functions using the growthcurver package in R (Sprouffske and Wagner 2016) based upon assumptions of the marginal value theorem and foraging theory (Charnov 1976; Stephens and Krebs 1986).

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Data analyses

To compare the characteristics of gathering sites across fire type (wild, cultural), territory (Karuk, Yurok, Hupa), ownership (private, Tribe, USDA Forest Service), and site quality (good, poor), I employed Chi-square tests of independence. Travel distances to hazelnut gathering sites within cultural burn, wildfire, and unburned locations were compared using a Wilcoxon rank sum test. Qualitative evaluations of basketry stems, hazel nut productivity, gathering, and burn efficacy were assessed to identify themes using an inductive analysis of field notes and interview transcriptions.

To evaluate the effects of growing seasons post-burn on hazelnut basketry stem production, I employed a negative-binomial generalized linear mixed model (GLMM) using the glmmTMB package in R (R Core Team 2014; Magnusson et al. 2017) and used Type III Wald Chi Square tests using the car package (Fox and Weisberg 2018) to perform backward model selection. Growing season post-burn (class), aspect (class), elevation, sample year, basal area (>10 cm dbh), precipitation, dominant tree (class), and slope were modeled as co-variate direct effects, and the plot was set as a random effect.

Additional variables that only applied to plots surveyed one growing season post-burn were analyzed by developing another negative-binomial GLMM, performing the same backward model selection process. The initial model set the plot as a random effect and included the following co-variate direct effects: proportion of ungulate browse, burn char height, burn season (winter, spring, summer, and fall), pre-burn total stems, precipitation, canopy cover, basal area (>10 cm dbh), elevation, aspect (east, south, southwest, and west), dominant tree, sample year, and slope.

To examine average stem diameter and length of basketry stems within shrubs surveyed after one growing season since burn, we selected gamma distributed GLMMs, as length and diameter distributions were skewed toward smaller sizes. Potential explanatory variables that were treated as direct effects in the initial stem diameter model were: basal area (>10 cm dbh), plot canopy closure, annual precipitation, aspect, slope, dominant tree species (>10 cm dbh), and burn season (e.g., fall, winter, spring, summer). The same explanatory variables were included in the initial stem length model, with the addition of ungulate browse proportions. As with other GLMMs, the plot was set as a random effect, and Type III Wald Chi Square tests were used to perform backward model selection.

To assess the density of hazelnut shrubs within plots (n = 46), we applied a multi-variate gamma generalized linear model using Type II Wald Chi Square tests to perform backward model selection. Burn frequency (either <3 burns or ≥3 burns from 1989 to 2019), basal area (>10 cm dbh), canopy closure, dominant tree species (>10 cm dbh), elevation, aspect, and slope were all evaluated as potential explanatory variables. Additional Wilcoxon rank sum and chi-square tests were employed to evaluate additional relationships between explanatory variables and hazelnut shrub density.

Model diagnostics were analyzed using the DHARMa package in R (Hartig 2019). To analyze the differences within categorical predictor variables that showed significance in the GLMMs, Estimated Marginal Means (hereafter Marginal $\bar{x}$) were generated and then 95% confidence intervals were compared using the Tukey method using the emmeans package (Lenth

2018). Marginal $\bar{x}$ values for categorical values are averaged over the values of other significant model co-variates, which helps account for significant imbalances in sampling effort. The sjPlot package (Lüdecke 2019) was used to analyze and visualize the effects of significant continuous predictor variables in the GLMMs.

RESULTS

Hazelnut basketry stem productivity

Growing season post-burn generated significantly distinctive marginal means amongst the three temporal classes, averaged over the values of sampled years ($p < 0.0001$, Fig. 12). Hazelnut shrubs growing only a single season post-burn produced a 13-fold increase in basketry stems (Marginal $\bar{x} = 10.776$, $\sigma_{\bar{x}} = 0.87$) than shrubs with three or more growing seasons post-burn (Marginal $\bar{x} = 0.801$, $\sigma_{\bar{x}} = 0.08$), and 6-fold greater stems than shrubs two growing seasons post-burn (Marginal $\bar{x} = 1.807$, $\sigma_{\bar{x}} = 0.25$). Along with these temporal differences, canopy tree basal area and burn season emerged as significant co-variates. Basketry stem production displayed a negative relationship with canopy tree basal area (>10 cm dbh, $p < 0.01$, Fig. 13) while sample years exhibited significant differences in basketry stems due to imbalances in yearly burning ($p < 0.001$).

Within shrubs growing only one season post-burn, pre-burn total stems had a strong positive relationship on basketry stem production ($p < 0.0001$, Fig. 14), whereas ungulate browse had a strong negative relationship with basketry stem production ($p < 0.0001$, Fig. 15). Burn season ($p < 0.01$) and aspect class ($p < 0.05$) also emerged as significant co-variates in the single season post-burn model of best fit. Shrubs burned in the winter (Marginal $\bar{x} = 15.54$, $\sigma_{\bar{x}} = 1.73$) produced 1.67-fold greater basketry stems than shrubs burned in the spring (Marginal $\bar{x} = 9.32$, $\sigma_{\bar{x}} = 1.05$, $p < 0.01$), and 1.43-fold greater basketry stems than shrubs burned in the fall (Marginal $\bar{x} = 10.89$, $\sigma_{\bar{x}} = 0.92$, $p < 0.05$). No other seasonal comparisons exhibited significant differences. Shrubs located in southern aspects produced a 1.7-fold increase in basketry stems (Marginal $\bar{x} = 13.62$, $\sigma_{\bar{x}} = 0.99$) than those found in eastern aspects (Marginal $\bar{x} = 8.01$, $\sigma_{\bar{x}} = 1.23$, $p < 0.05$). However, marginal means amongst shrubs in other aspects did not differ significantly. Burn char height (range = 0 – 9 m), dominant canopy tree, canopy closure, precipitation, elevation, and slope were insignificant predictors of basketry stem production.

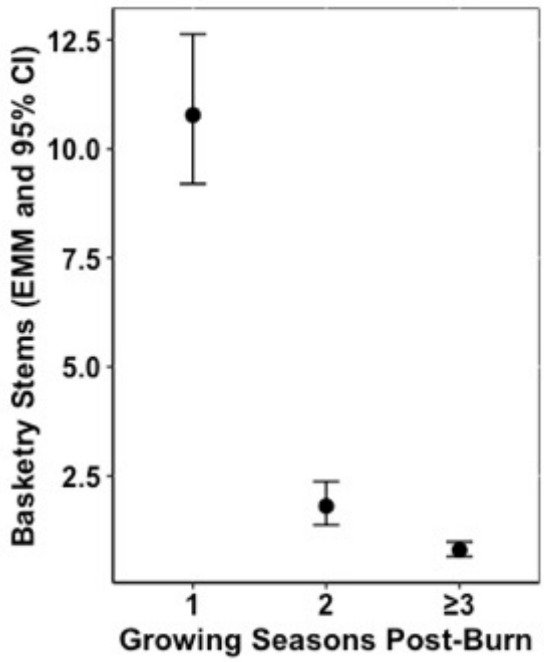

Figure 12. Hazelnut Basketry Stem Production and 95% CI with Growing Seasons Post-Burn.

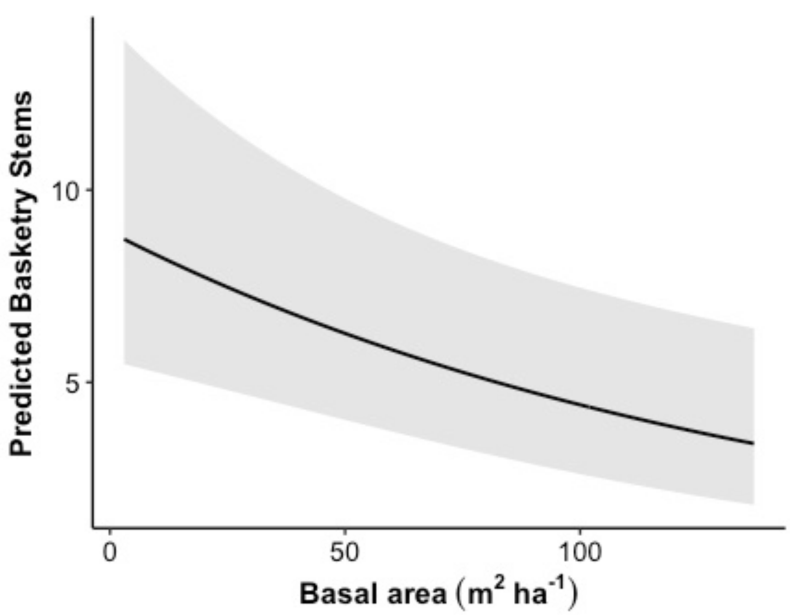

Figure 13. Proportion of Hazelnut Shrub Browsed with Predicted Basketry Stem Production Values (95% CI grey) from 1-year Post-burn Temporal Class.

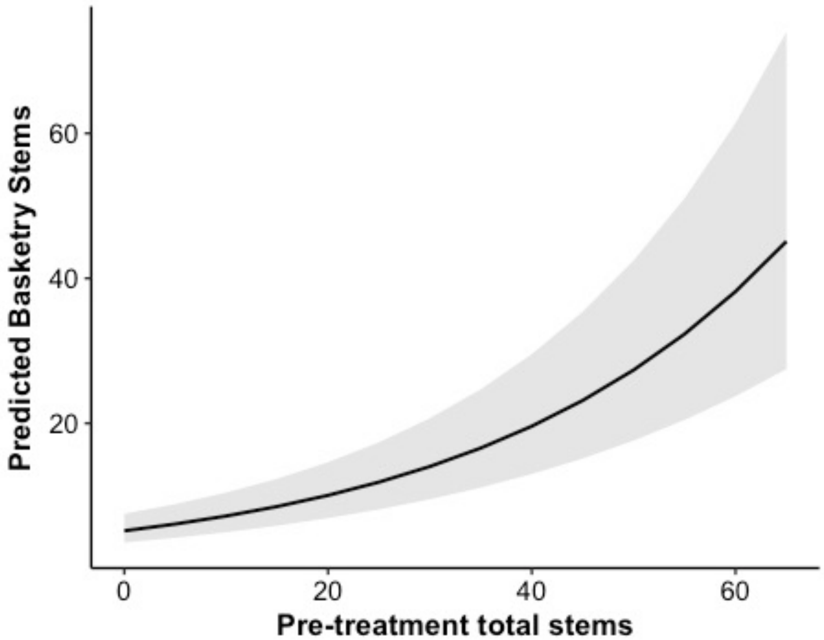

Figure 14. Hazelnut Shrub Size (pre-treatment total stems) with Predicted Post-treatment Basketry Stem Production Values (95% CI grey) from 1 Year Post-burn Temporal Class.

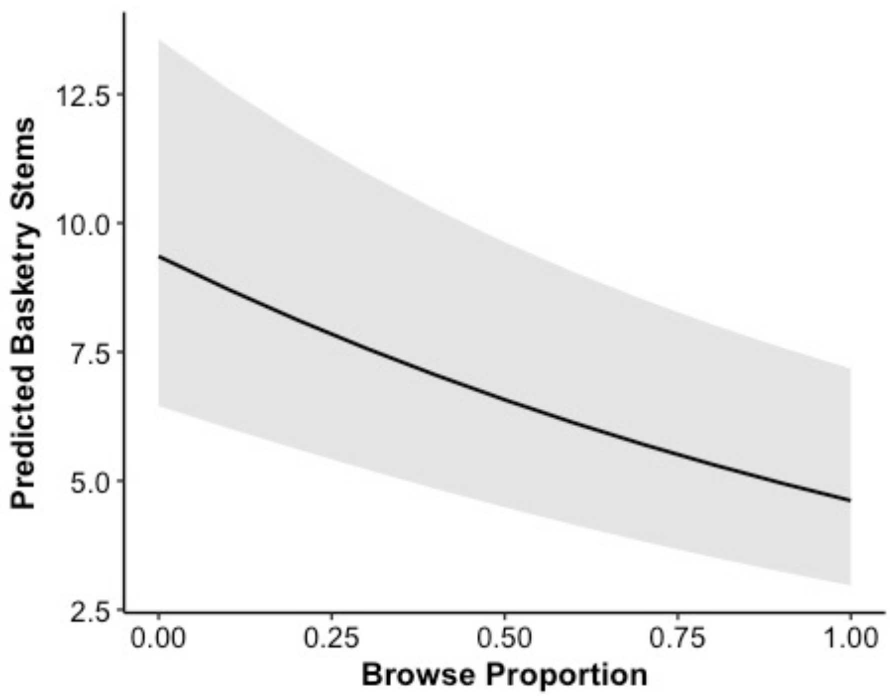

Figure 15. Predicted Hazelnut Basketry Stem Production (95% CI grey) with Canopy Tree Basal Area (>10 cm dbh) Including all Temporal Growing Season Classes (1, 2, and >3 growing seasons post-burn).

Hazelnut shrub density

Hazelnut shrub density within plots was most strongly correlated to burn frequency, aspect, and elevation. Plots that were burned ≥ 3 times from 1989 - 2019 had 1.86-fold greater hazelnut shrubs (Marginal $\bar{x} = 71.0$, $\sigma_{\bar{x}} = 9.53$) than plots burned < 3 times (Marginal $\bar{x} = 38.1$, $\sigma_{\bar{x}} = 4.02$, $p < 0.0001$, Fig. 16). Plots within eastern aspects had 2.2-fold higher density of hazelnut shrubs (Marginal $\bar{x} = 93.5$, $\sigma_{\bar{x}} = 18.33$) than those growing in southern (Marginal $\bar{x} = 43.5$, $\sigma_{\bar{x}} = 3.99$) and southwestern aspects (Marginal $\bar{x} = 42.5$, $\sigma_{\bar{x}} = 4.86$, $p < 0.001$). Shrubs growing in western aspects grew at similar densities to eastern aspects (Marginal $\bar{x} = 69.9$, $\sigma_{\bar{x}} = 11.01$, $p = 0.66$), but did not exhibit densities that were strongly different from southern ($p = 0.056$) or southwestern ($p = 0.071$) aspects. Shrub densities decreased as elevations increased (range = 170 – 934 m a.s.l, $p < 0.05$). Although territory was not a significant co-variate in the multi-variate gamma GLMM, shrub densities in Yurok territory were 2.19-fold greater than shrub densities in Karuk territory, and a Wilcoxon rank sum test found the difference was significant ($p < 0.001$, Fig. 16). Additionally, basal area was insignificant in the gamma GLMM, but displayed a negative relationship with shrub density in univariate analysis ($p < 0.05$).

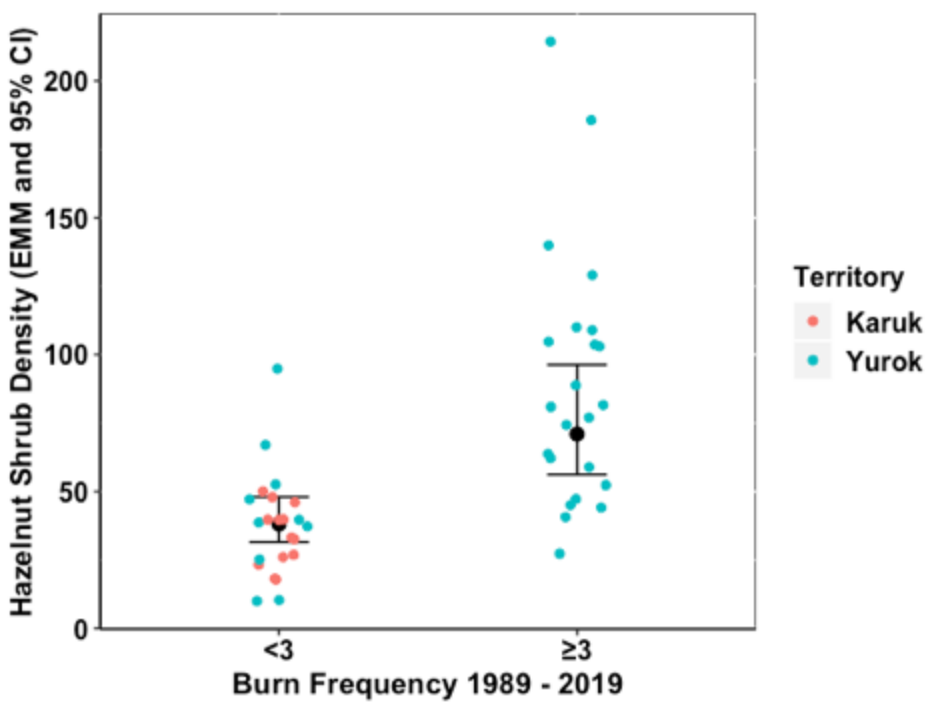

Figure 16. Hazelnut Shrub Densities with Burn Frequencies (<3 and ≥3) from 1989-2019. Marginal Means with 95% CI ($p < 0.0001$) and plotted data points colored according to location within Karuk or Yurok ancestral territory (Figure 11A).

Basketry stem length and diameter

Burn season ($p < 0.01$) and basal area ($p < 0.0001$) were significant co-variates affecting basketry stem diameters (Fig. 17). As canopy tree basal area (> 10 cm dbh) in plots increased, it had an inverse effect on stem diameter. Burning in the summer produced larger stem diameters (Marginal $\bar{x}$ = 4.54 mm, $\sigma_{\bar{x}}$ = 0.32) compared with spring (Marginal $\bar{x}$ = 3.08 mm, $\sigma_{\bar{x}}$ = 0.25, p = 0.003) and winter (Marginal $\bar{x}$ = 3.64 mm, $\sigma_{\bar{x}}$ = 0.25, p = 0.037). Basketry stem lengths were significantly affected by basal area, percent ungulate browse, dominant overstory tree, and burn season. Canopy basal area ($p < 0.001$, Fig. 18) and percent ungulate browse ($p < 0.0001$) were both negatively correlated with stem length. Burning in the spring produced significantly shorter stems (Marginal $\bar{x}$ = 0.524 m, $\sigma_{\bar{x}}$ = 0.057) compared with all other seasons (all = $p < 0.05$). Stems growing beneath canopies dominated by broadleaf hardwoods were significantly longer (Marginal $\bar{x}$ = 0.83 m, $\sigma_{\bar{x}}$ = 0.062) than stems growing beneath coniferous canopies (Marginal $\bar{x}$ = 0.65 m, $\sigma_{\bar{x}}$ = 0.051, p = 0.035, Fig. 18).

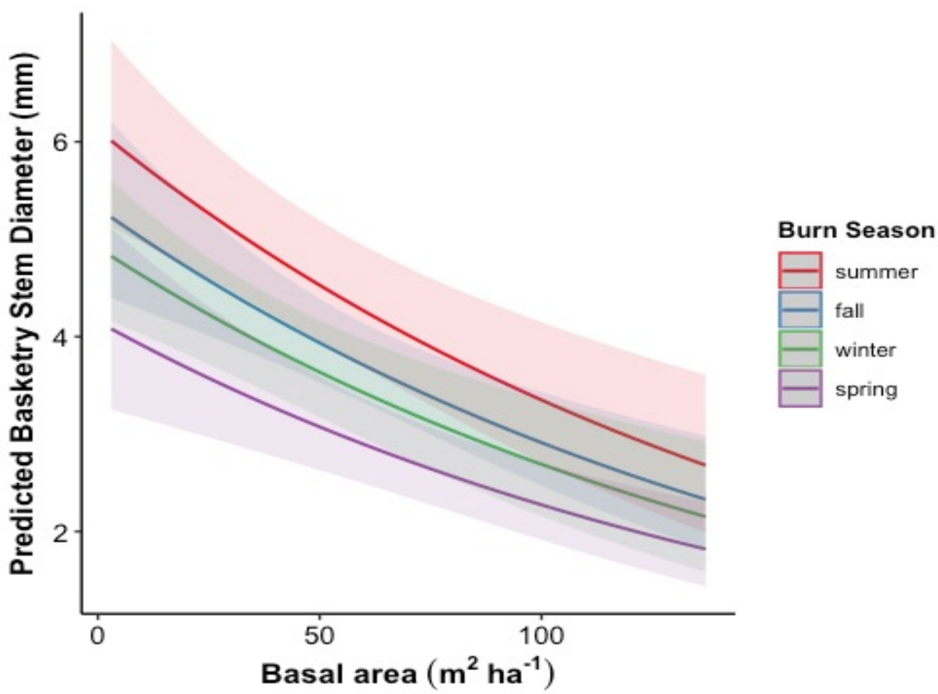

Figure 17. Canopy Tree Basal Area (>10 cm dbh) with Predicted Basketry Stem Diameters (95% CI) and Burn Season (summer, fall, winter, and spring). Shrubs burned in the summer (Day 172 ± 1 to Day 266 ± 1) produced significantly larger stem diameters than those burned in the spring (Day 79 ± 1 to Day 172 ± 1; $p < 0.01$) and winter (Day 355 ± 1 to Day 79 ± 1; $p < 0.05$). Stem diameters exhibit a negative relationship with canopy basal area ($p < 0.0001$).

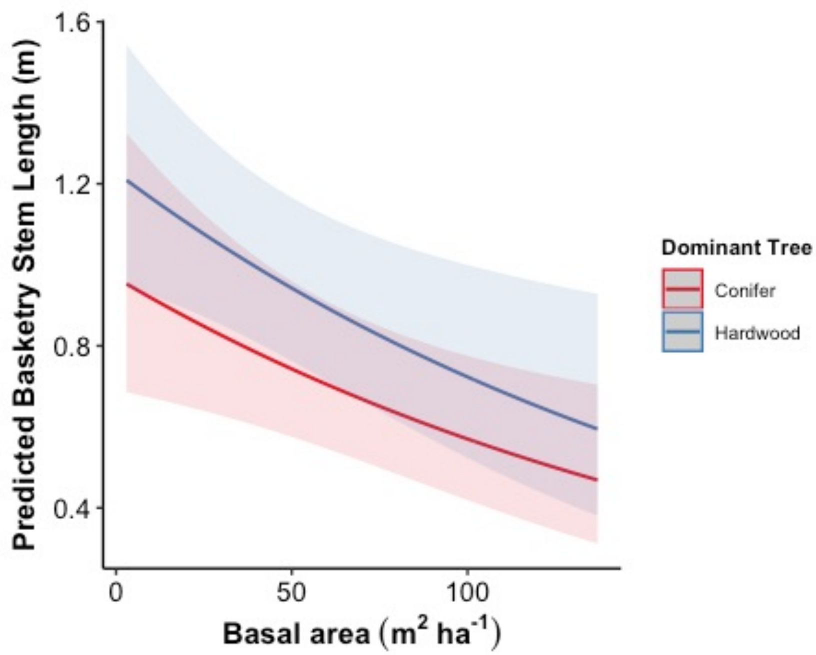

Figure 18. Canopy tree basal area and dominant canopy tree (>10 cm dbh) with predicted hazelnut basketry stem length (95% CI). Hazelnut basketry stems growing under hardwood canopies were significantly longer than stems growing under coniferous canopies ($p < 0.05$). Stem lengths exhibited a strong negative relationship with canopy basal area ($p < 0.001$).

Hazelnut basketry stem gathering

Gathering hazelnut stems is an intergenerational activity that brings together friends and relatives, and basketweaving teachers and their students (Fig. 19). From 2015 to 2019, 90 distinct individuals were observed gathering hazelnut stems. Observed hazelnut basketry stem harvesters were 75% women, and, on average, gathered in groups of 3 (n = 31: range = 1 – 8 individuals). The majority (57%) of gathering groups were intergenerational, with a mix of elders (>60 years), middle-aged gatherers (25 – 60 years), and youth (<25 years, n = 30), and 66% of groups were composed of basketweaver mentors and their students (including familial mentorships). Of all recorded trips, 63% were conducted with family members, 21% were with friends, and 17% were solitary (n = 72). When particular burn sites generated exceptional quantities of basketry stems, basketweavers invited family and friends across the inter-tribal basketweaving community to come and harvest. Hence, an individual's social network appeared to mediate resource access. Otherwise, individuals respect Tribal territory and familial ownership when selecting gathering sites. Gathering trips to 'good' sites were much more frequent (87% of all trips) than to 'poor' sites (13%, n = 89). Of the 12 trips to 'poor' sites, five of the trips were to gather at sites two growing seasons post-burn, and one trip was to a fire excluded site (unburned for >30 years). The majority of trips (73%) were to sites that were burned ≥3 times between 1989 and 2019. Stem harvesters were more likely to evaluate gathering sites on USDA Forest Service owned sites as 'poor' compared with other ownerships ($p < 0.001$). Of all cultural burn sites ($n = 4$) on USDA Forest Service sites, 75% were evaluated as 'poor' due to heavy browse by ungulates, whereas wildfire sites on Forest Service land were all evaluated as 'good' ($n = 4$).

All hazelnut basketry stems were gathered within a few weeks of bud break, which spanned between spring solstice (March 20/21) to early May, depending on the site aspect and elevation. The majority of basketweavers I observed are either retired (14%) or employed by the Tribes, Forest Service, and local school districts (78%). While some positions provide flexible work hours that enable the gathering of ecocultural species like hazelnut, most hazelnut stem gathering observed here occurred on the weekends (84% of gathering trips). Basketweavers expressed that they would prefer to gather close to home, but few suitable burned hazelnut groves were located in close proximity to their residences. Three basketweavers noted that although they had relatively small patches (< 500 m^2) of hazelnut on their landholdings that they regularly burned, these sites produce insufficient quantities of basketry stems to satisfy the needs of basketweavers. Furthermore, productive shrubs in one year cannot be productive the following year, if they are on the more common fall burning cycle. Thus, individuals with small patches on their properties needed to gather at other burned sites to support their weaving.

Out of all stem gatherers, I received reports and made harvesting observations with six individuals consistently between 2016 and 2019. Only one of these individuals gathered exclusively in Karuk territory, and the other five individuals consistently gathered in Yurok territory. The five that gathered in Yurok territory, on average gathered at 1.4 burn sites between 2016 and 2018 (range of total distinct sites = 3 – 5), and in 2019 visited 2.8 sites (six distinct sites visited). Four of these basketweavers reported that they took five or more gathering trips within the hazelnut gathering season.

Gathering hazelnut stems requires a considerable commitment if burned areas are distant and the presence of quality hazelnut stems is unknown. Because some basketweavers now reside relatively far from ancestral territories and burned hazelnut groves, basketweavers were observed to travel considerable distances to gather. Harvesters traveled a median distance of 34 km one-way (range: 0 – 472 km) per trip to gathering patches ($\bar{x} = 60 \pm 10.9$ km, $n = 49$). Basketweavers travelled 3.8-fold greater distances to reach wildfire gathering sites ($\bar{x} = 129$ km, $\sigma_{\bar{x}} = 40$ km) than to cultural burn areas ($\bar{x} = 38$ km, $\sigma_{\bar{x}} = 6$ km, $p < 0.01$). On average, gatherers spent 56 ± 16 minutes in a hazelnut stem gathering site. At prescribed burn sites, mean gathering rates were 4.9

stems/minute/individual ($n = 22$) while gathering rates recorded at wildfire locations ($n = 4$) were reduced to only 1.6 stems/minute/individual, and at the fire excluded site the gathering rate was 0.5 stems/minute/individual (Fig. 20). From 2015 - 2019 basketweavers and stem gatherers selected 21 independent burn areas; 76% of these sites were culturally burned and 24% were burned by wildfires. Of these sites, 29% were on USFS land, 48% were privately owned, and 23% were Tribally owned fee or trust lands (Yurok and Hoopa Valley reservations). The majority of gathering trips recorded occurred at culturally burned sites in Yurok territory (78%, $n = 89$). Trips in Yurok territory all occurred at culturally burned sites, whereas trips to gathering sites in Karuk and Hupa territories were significantly more likely to occur at wildfire sites (50% of all trips, $n = 20$, $p < 0.0001$).

While wildfires in this region burn hazelnut shrubs, basketweavers remarked that searching for hazelnut shrubs in these typically remote wildfire areas requires considerable additional time. Ms. Verna Reece, a renowned Karuk basketweaver and teacher, consistently shared that she is one of the few gatherers who invests the necessary time and effort to drive the roads through burn areas in Karuk territory to scout and locate suitable hazelnut groves. Because Verna shares identified locations of hazelnut patches within wildfire areas, many of her students benefit from her initial reconnaissance and knowledge of local fire history. I observed three hazelnut gathering trips that Ms. Reece led, and heard 4 reports of additional gathering trips that she facilitated. On these trips Ms. Reece always brought at least two of her students with her. The trip with the most students occurred during the annual Karuk basketweavers gathering in 2017, and she brought >30 individuals to gather hazelnut basketry stems in an area that was routinely mechanically cut to reduce roadside fuels.

Basketweaver observations of reduced hazelnut stem quality in spring burned hazelnut groves impart their relatively low preference for those harvesting areas as they are deemed to be “burned at the wrong time”. Other sites that were assessed as relatively poor quality were those that were heavily browsed by deer and elk (native ungulates), and those sites that were not burned at a sufficient intensity. At low intensity burn sites gatherers found that basketry stems were challenging to access due to the limited consumption of underbrush and surface and ladder fuels (e.g., down logs with branches/limbs, or small trees and shrubs). Basketweavers also noted that shrubs burned in the winter and spring produced stems that were smaller in diameter and shorter in length than those burned in the summer or fall, because of the reduced period between burning and gathering.

In contrast to years of relative abundance, when there are limited burned areas for basketry stem gathering, such as in the spring of 2015, the locations of basketry stems are not readily shared, and basketry classes have a scarcity of resources. Under these circumstances, territoriality is much more palpable. For example, at one gathering site on a privately-owned parcel in Yurok territory, initially only family members had permission to gather basketry stems, however, once the family realized there were a surplus of stems, then other Yurok Tribal members were invited to gather, and eventually Karuk and Hupa Tribal members were also invited. Nevertheless, the majority of basketweavers do not feel comfortable gathering within the territory of other Tribes, unless they have a direct or close relationship with someone of that Tribe.

Basketweavers report several obstacles to increasing hazelnut grove burning, most notably the displacement of Indigenous peoples from their lands and the subversion of Tribal sovereignty. Non-Indian private landowners continue to prioritize timber and *Cannabis* production, and thus, former hazelnut gathering areas have become overgrown and displaced by other resources. Several basketweavers expressed that the persistence of racism, as well as its ongoing manifestations of harassment, imprisonment, and violence toward Indigenous peoples for gathering, hunting, and burning on their lands makes them hesitant to gather hazelnut stems, despite USFS policy changes that permit Indigenous gathering. One basketweaver noted that as recently as 2016, a Yurok Tribal member was fined for gathering by a California State Park ranger in Yurok ancestral territory. Another basketweaver recounted that private landowners harassed basketweavers in 2018 for gathering materials near national forest roads on privately-owned parcels. Despite this harassment, several weavers remarked that such harassment does not dissuade them, and that “gathering is necessary to exercise their sovereignty” as Indigenous peoples.

Figure 19. Intergenerational Hazelnut Basketry Stem Gathering. Photo by Frank Lake.

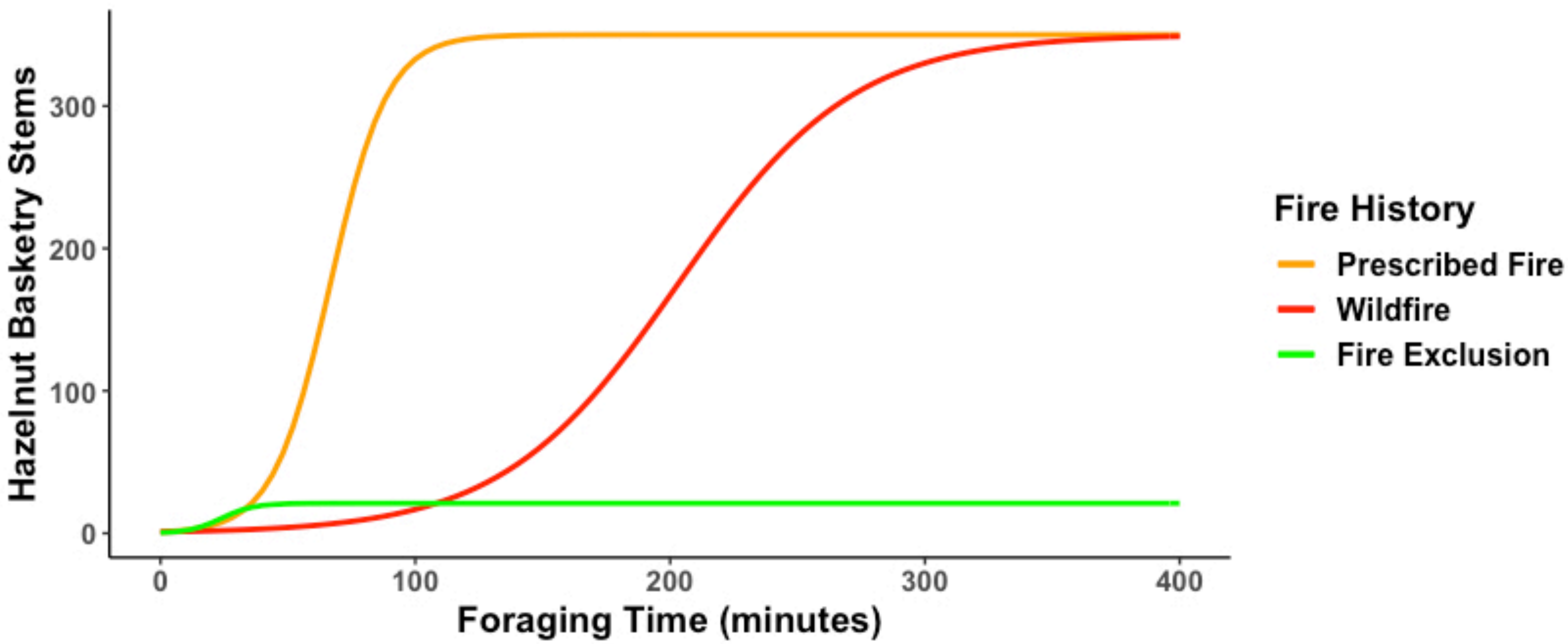

Figure 20. Fire History and Hazelnut Stem Gathering Rates Modeled as Logistic Functions. Foraging time includes travel and gathering time. Gathering rates are based on average rates observed in prescribed burn areas (5 stems/minute, n = 22), wildfire areas (2 stems/minute, n = 4), and fire excluded areas (0.5 stems/minute, n = 1). Travel time to gathering areas was calculated from the average distance travelled one-way (34 km, prescribed burn; 129 km, wildfire [n = 11]; 2 km, fire exclusion) at a rate of 80 km/hour. The model assumes a gatherer aims to harvest 350 stems, based upon the average harvest observed from trips to nine prescribed burn areas. In areas where fire has been excluded for ≥3 years, basketry quality stem density is significantly reduced (Fig. 2), and thus, these sites impart highly reduced gathering rates. In areas burned by wildfires, stem gatherers travel 3.8-fold greater distances, and reportedly spend additional time locating hazelnut shrubs. Additionally, harvest rates may be reduced due to decreased shrub densities (Fig. 9). In contrast, stem gatherers travel shorter distances and have increased stem gathering rates in cultural burn areas that are frequently burned, where hazelnut shrub densities are 1.86-fold greater than wildfire sites.

DISCUSSION

Ecology of basketry stem production and hazelnut shrub density

Karuk and Yurok burning of hazelnut shrubs greatly increases basketry stems one growing season post-burn compared with ≥ 3 growing seasons post-burn. This suggests that cultural burning for basketry stem production would be optimized at short intervals (e.g., every 3 – 5 years). This strongly concurs with California Indian basketweaver knowledge of hazelnut fire ecology, and practice of cultural burning (O'Neale 1932; Thompson 1991; Ortiz 1998; Anderson 1999), and aids the interpretation of regional fire history studies regarding fire frequency and seasonality of the ancestral territories of Tribes who use hazelnut stems in basketry (F. Lake/E. Knapp USDA Forest Service unpublished data; Fry and Stephens, 2006; Taylor and Skinner, 2003, 1998).

Higher densities of hazelnut shrubs occur in areas that have burned ≥ 3 times in 30 years, creating a higher density of basketry stems in these areas one growing season post-burn compared with hazelnut groves where fire has been excluded and densities are lower. Greater shrub density and basketry stem production in areas with relatively less canopy basal area also suggest that short interval burning would benefit hazelnut shrubs, as these canopy conditions are promoted by frequent, low-intensity fire regimes (Stephens and Fulé 2005; Scholl and Taylor 2010). Given the vital importance of hazelnut stems in Karuk and Yurok culture, and many other regional tribes, burning for hazelnut undoubtedly affected the abundance of hazelnut across the pre-colonial landscape. The greater density of hazelnut shrubs at lower elevations may be an artifact of the historical settlement of Karuk and Yurok villages along the Klamath river (Waterman 1920; Kroeber 1936) and the repeated cultural burning of hazelnut groves in close proximity to villages and favored resource camps.

A staggered, low intensity, and frequent cultural fire regime, like that proposed by Lightfoot and Parrish (2009), maintains hazelnut groves in a steady ecological state (Botkin and Sobel 1975; Petraitis and Latham 1999; Beisner et al. 2003). This socio-ecological system is akin to the burned areas that Lewis and Ferguson (1988) referred to as "fire yards and corridors" that were regularly burned to maintain prairies. However, in this case these yards are not anthropogenic prairies, but the park-like forests often described by early European settlers (Sudworth 1900; Leiberg 1902; Pyne 1982; Muir 2008). Unlike anthropogenic burning in the spinifex desert of Australia, or the swidden Mayan milpa that creates a shifting successional mosaic (Bliege Bird et al. 2008; Nigh and Diemont 2013), hazelnut groves are maintained by frequent low-intensity burning, that halts successional processes. The focal ecocultural species in a hazelnut grove is woody and has a re-sprouting life history, which suggests that a distinct burning regime is required to maintain hazelnut, compared to a 'yard' of herbaceous perennials or annuals.

This socio-ecological model was described in 1916 by Lucy Thompson, a Yurok woman, who stated that, "The Douglas fir timber…has always encroached on the open prairies and crowded out the other timber; therefore they have continuously burned it" (Thompson 1991: 33). This finding was further developed and articulated as a state and transition model by Huntsinger and McCaffrey (1995) that included woodlands, but did not address important understory ecocultural species, like hazelnut. Similarly, other ecological studies in northern California montane forests have found that repeated burning by lightning fires maintain steady shrubland states (Odion et al. 2010; Lauvaux et al. 2016), and that in the absence of fire, oak woodlands convert to Douglas fir stands (Hunter and Barbour 2001; Engber et al. 2011; Schriver et al. 2018). Hence, this fire-mediated dynamic is quite prevalent in the region, and supports the finding that hazelnut is less abundant in the absence of frequent fire.

The maintenance of hazelnut groves, for basketry in open forests, and for nuts in more shrub dominated patches, through repeated cultural burning is an excellent example of how California Indian resource management has been critical to ecological dynamics throughout California (Lightfoot and Parrish 2009; Anderson 2018). Cultural burning produces a positive-feedback ecological relationship (Bliege Bird 2015), between basketweavers and hazelnut and is evidence of human niche construction and ecosystem engineering by California Indians (Jones et al. 1994, 1997; Smith 2011; Odling-Smee et al. 2013). In this case, cultural burning increases the resource productivity of hazelnut shrubs and basketry stems for basketweavers, and also increases quality forage for ungulates (Lawrence and Biswell 1972; Kie 1984; Long et al. 2008), and nut production for humans and wildlife (Lake 2007; Fine et al. 2013; Armstrong et al. 2018). Anthropogenic patch mosaic burning by Australian Aborigines to improve hunting is another example of human niche construction that has been shown to increase habitat edge density and wildlife abundance (Bliege Bird et al. 2013; Codding et al. 2014).

The expansion of cultural burns for a suite of fire-enhanced ecocultural resources would have cascading effects on species diversity and populations, and likely positive effects for a diversity of wildlife including endangered species like the California condor and Spotted Owl that feed in edge habitats and clearings (Cowles; Biswell 1999; Franklin et al. 2000; Roberts et al. 2011; Nabhan and Martinez 2012; Eyes et al. 2017). In the absence of cultural burning (fire exclusion), hazelnut and countless other understory species are compromised (Webster and Halpern 2010; Knapp et al. 2013; Wynecoop et al. 2019), along with the Indigenous fire-dependent cultures that rely on these species and processes (Heffner 1984; Ortiz 1993; Mathewson 2007; Smith 2016).

Basketry stem quality and ecology

As cultural burning expands within a drastically altered ecological, climatic, and political context in California, evaluating the effects of ecological and fire variables on the production and quality of hazelnut stems may serve to refine future burning decisions. Our data show that canopy basal area, dominant canopy tree, and burn season all influence hazelnut basketry stem length. Post-burn basketry stem qualities are important to basketweavers, who need a variety of stems of different lengths and diameters depending on what they intend to weave (O'Neale 1932; Lake 2007: 243). Longer stems have more functionality than shorter stems, as they can be cut to shorter lengths depending upon the basketry project (V. Reece, pers. com., 2018). Therefore, our measurements of stem diameter and length may help fire managers and basketweavers identify and prioritize forest stand characteristics, burn season, and the frequency of cultural fires in hazelnut groves.

Canopy basal area is negatively correlated to stem length, and hardwood canopies supported longer stem lengths (on average 18 cm longer), compared with coniferous canopies. These relationships may be attributed to greater understory light transmittance in forest stands with lower basal area, and broadleaf trees such as oaks (Fralish 2004; Barbier et al. 2008). Given that lower basal areas also support overall basketry stem production, canopy thinning in hazelnut groves would likely improve quality and quantity of basketry stems. Targeting coniferous species for thinning would also support the growth of encroached hardwoods, whose populations have become compromised by Douglas fir in the region (Hunter and Barbour 2001; Engber et al. 2011; Cocking et al. 2012; Schriver et al. 2018).

Shrubs that were burned in the spring produced significantly shorter stems compared to all other burn seasons. This is attributed to the truncated growing season caused by these burns, which occurred after bud break. Although shorter length stems are less functional, stems burned in the spring also have a smaller diameter, which is a desired quality for basketweavers producing baskets that require a tight weave (e.g., basket caps; Johnson and Marks, 1997). Hence, this trade-off may be preferred by some basketweavers. The stem wood to pith ratio is also different among spring vs. fall burned hazel shoots, which affects the tensile strength and durability for use in weaving (Rentz 2003; Lake 2007). However, spring burning raises concerns for some Tribal members as burning during this season may negatively affect wildlife and was less common preceding colonialism (Knapp et al. 2009; Marks-Block et al. 2019). Tribal members have also taken advantage of recent winter droughts (Griffin and Anchukaitis 2014) and dry periods to increase cultural burning for hazelnut basketry stems. Stems produced from these burns also had a smaller diameter compared with summer burns, and were longer than those stems burned in the spring. Hence, finding good burning opportunities in the winter may produce stems of desirable qualities, without the potential negative effects of burning after the spring equinox.

Ungulate browse also shortened stems and initiated lateral stem branching, reducing the functionality and quality of stems. When there were high proportions of browsed stems at cultural burn sites, basketweavers rated their quality as poor, and few basketweavers selected these sites for gathering. While browse occurs at all sites, if burning is done near residences, the nearby presence of dogs and people may discourage interspecies competition for post-burn hazelnut resprouts, and have the added benefit of reducing wildfire hazards. Additionally, expanding the frequency and area of cultural burn sites, and allowing wildfires to burn for resource objectives and socio-ecological benefits, may reduce interspecies competition for hazelnut resprouts by providing sufficient high quality browse for ungulates across the landscape (Wan et al. 2014).

Basketry stem gathering and governance

Cultural burning directly supports the maintenance and revitalization of Northwest California Indian basketweaving by reducing the costs associated with basketry stem gathering. Foraging efficiencies are greatly improved by burning, and subsequently inform the selection of basketry stem gathering sites. Basketry stem gathering rates are 10-fold greater in cultural burn areas compared with fire-excluded hazelnut groves, leaving little incentive to gather in unburned areas (Anderson 1999). Without accounting for the increase in travel time to wildfire areas, cultural burn areas generated gathering rates that are 3-fold greater than those in wildfire areas, which we attribute to greater shrub densities associated with repeated cultural burning. Accordingly, stem gatherers selected burn sites of higher quality more frequently than those areas of poor quality and lower shrub densities. This is strong evidence that stem gatherer decision-making adheres to the most basic optimal foraging theories of maximizing efficiency (Stephens and Krebs 1986).

However, land dispossession and limited Tribal autonomy over burning have caused stem gatherers to select less than ideal gathering sites. In Karuk territory land dispossession has been comparatively greater than in Yurok territory, thus in recent decades Tribal members have not been able to maintain as many hazelnut groves with consistent cultural burning. Collaborative burning between the Karuk Tribe and the USDA Forest Service tends to fluctuate with staff who are supportive of burning, but who often move from the region to advance their careers (Diver 2016; Smith 2016). The sites where these collaborative burns occurred from 2015 - 2019 have predominantly been in remote locations where canopy basal area is relatively high, shrub densities are relatively low, and deer and elk ungulate browse has been heavy. As a result, Karuk stem gatherers tend to gather in areas burned by wildfires, where they have found higher quality basketry stems. However, compared with culturally burned sites in Yurok territory, the gathering costs are higher due to increased travel and lower shrub densities.

Gatherers generally do not harvest in hazelnut groves belonging to other families or in Tribal territories where they do not have social ties or permission. Hence, while there are higher quality groves in Yurok territory, unless individuals have Yurok ancestry or are invited by Yurok friends and family, they will gather at lower quality hazelnut groves to respect land tenure. This social dynamic is reflective of the decentralized Karuk and Yurok governance structures preceding colonialism where usufruct rights to resource tracts were organized at the level of families and individuals (Waterman 1920; Thompson 1991; Huntsinger and Diekmann 2010; Bettinger 2015).

The centralization of resource and fire management by the US government and the fragmentation of Tribal land ownership pose major challenges to increasing access to ecocultural resources like hazelnut basketry stems (Huntsinger and Diekmann 2010). Nonetheless, Karuk and Yurok Tribal members have initiated successful burning programs that are reducing the relative scarcity of hazelnut stems and supporting cultural revitalization. To adjust to these new modes of governance, Tribes have developed their own Natural Resource departments and wildland fire departments, and have established partnerships with the USDA Forest Service to co-manage fire and resources (Long and Lake 2018). Tribal basket weavers have also self-organized to form organizations such as the California Indian Basketweavers Association (LeBeau 1998; Kallenbach 2009) and Karuk Indigenous Basketweavers to address the need for cultural burn partnerships. In Karuk territory these partnerships have supported the development of long-term cultural fire restoration projects that intend to initiate regular repeated burns in hazelnut groves (USDA Forest Service PSW Region 2018).

In Yurok territory, basketweavers and their families have initiated a successful cultural burning program that has reduced the relative scarcity of hazelnut stems. The Cultural Fire Management Council (CFMC) began to annually burn hazelnut groves in 2013, and supported families and the Tribe in maintaining regular burns. In 2019, the CFMC President, Margo Robbins, shared that, “Ten years ago it wasn’t often that you’d see a baby in a basket. Now there are lots of babies in baskets because of TREX”. Basketweavers like Margo articulate a clear connection between burning and its role in supporting cultural revitalization.

Partnerships between Tribes, NGOs and government agencies have supported the contemporary burning of hazelnut groves, much like collaborative burning projects in South America and Australia (Fache and Moizo 2015; Mistry et al. 2019; Neale et al. 2019), but greater Tribal sovereignty and familial autonomy over burning in ancestral lands will ensure its maintenance and expansion (Baldy 2013; Robbins et al. 2016). In regions where cultural burning is less frequent due to legacies of fire exclusion, prescribed fire managers could prioritize the revitalization of these practices in collaboration with American Indian communities (Lake et al. 2017; LeCompte 2018; Long and Lake 2018; Lewis et al. 2018; Wynecoop et al. 2019).

The revitalization of Karuk and Yurok cultural burning is an alternative model for restoring fire and ecological function to landscapes that experienced fire exclusion and industrial timber extraction. Compared to restoration initiatives focused upon conservation and hazardous fuel reduction, California Indian initiatives are primarily tied to restoring ecocultural species for cultural, spiritual, and subsistence use. The firing practices of Indigenous and place-based fire-dependent cultures may be more effective at restoring the desired reference landscapes that conservation organizations and public land agencies aim to recreate, because their practices were partially responsible for the historical, more predominately cultural fire regime (Kimmerer 2011; Lake 2013; Bliege Bird and Nimmo 2018). Moreover, Tribes, resource users, and local entities appear to be well equipped to maintain burning over the long-term, compared to centralized bureaucracies whose budgets and political orientations are in constant flux. The cultural burns observed here indicate that this fire governance model has great potential to support fire-adaptive socio-ecological communities (Abrams et al. 2015; Roos et al. 2016).

CHAPTER 5

Maintaining California Black Oak (*Quercus kelloggii*) Woodlands with Cultural Fire in Karuk and Yurok Territories in Northwest California

ABSTRACT

Cultural fires are intentionally set fires to maintain the abundance and quality of species and habitats fundamental to California Indian livelihood and culture. Historically, California Indians repeatedly burned the understories of California black oak (*Quercus kelloggii*) woodlands to improve the gathering efficiency of acorns and other understory species. In northwest California, the Karuk and Yurok Tribes are revitalizing cultural burns, in part to maintain black oak and other hardwood species that, in the absence of burning, have been encroached by Douglas fir (*Pseudotsuga menziesii*), and suppressed to support timber plantations. In addition, cultural burns are being implemented to reduce hazardous fuel accumulations and wildfire risk given widespread fire exclusion policies. In some areas of Karuk and Yurok territory, cultural burning has persisted at high frequencies (≥ 3 burn events from 1989 – 2019). In this study we compare the overstory species composition, stand basal area (>10 cm dbh), and tree densities between these high cultural burn frequency sites, and sites where cultural burns have been recently re-introduced or proposed (low frequency sites: < 3 burn events from 1989 – 2019) using field surveys within 21 cultural burn sites and an analysis of deciduous tree cover from remotely sensed images. We also document the biophysical and climatic conditions during cultural burns, and evaluate whether cultural burns reduce surface fuels, and alter the density of Douglas fir seedlings and saplings. We find that high frequency burn events facilitate hardwood tree overstories predominantly composed of deciduous black oak ($p < 0.001$), and that at low frequency cultural burn sites Douglas fir dominated the overstory. Overstory tree basal area at sites dominated by Douglas fir was 1.85-fold greater than at sites dominated by hardwoods ($p < 0.0001$), and tree densities were 1.5-fold greater at low frequency burn sites compared with high frequency burn sites ($p < 0.01$). Small diameter surface fuels (0 – 25 mm) and Douglas fir seedlings and saplings were significantly reduced by cultural burns ($p < 0.01$). High frequency, low-intensity cultural burning is an effective means to maintain black oak woodlands, and supports California Indian livelihoods and culture.

INTRODUCTION

Preceding colonialism, California Indians intentionally set fires throughout the forests and woodlands of California that were fundamental to maintaining the abundance and quality of species critical to their livelihood and culture (Stewart 2002; Lightfoot and Parrish 2009; Anderson 2018). Acorns from oaks (*Quercus spp.*) and tanoaks (*Notholithocarpus densiflorus*) were a critical subsistence food for Indigenous Californians (Basgall 1987; McCarthy 1993; Tushingham and Bettinger 2013; Long et al. 2016), and the understories of these woodlands were prescriptively burned to diminish acorn insect infestations and reduce accumulations of woody fuels and brush, improving acorn gathering efficiency (McCarthy 1993; Halpern 2016). However, in the first three decades of the 20th century, such prescriptive burning was widely prohibited by fire exclusion policies, and California Indian lands were extensively dispossessed engendering massive ecological and cultural change (Pyne 1982; Huntsinger and McCaffrey 1995; Lightfoot and Parrish 2009; Norgaard 2019).

In northwest California, Tribal members can no longer rely on acorns or other fire-enhanced species for subsistence and cultural practices (Norgaard 2019; Sowerwine et al. 2019), because acorn quality has deteriorated without understory burning (Halpern 2016), and oak woodlands have been encroached by conifers or were converted to timber plantations (Strothmann and Roy 1984; Barnhart et al. 1996; Hunter and Barbour 2001; Cocking et al. 2012; Schriver et al. 2018). Yet, in Karuk and Yurok Indian territories (Fig. 21) prescriptive burning practices, colloquially called ‘cultural burning,’ were not completely eradicated, but persisted in small areas (< 10 ha) because of Indigenous land tenure and resolve to maintain the practice. Since 2013, cultural burning practices are being revitalized in the region through partnerships with the Fire Learning Network’s Prescribed Fire Training Exchanges and changes in state and federal fire management policies (Long et al. 2018b).

This resurgence of cultural fires generates a unique opportunity to evaluate their effects upon understory surface fuels (which mitigate fire intensity and rate of spread), and to compare the overstory forest composition and stand structure between sites with distinctive fire regimes: those sites where cultural burning events have been frequent and persistent for at least the past 30 years, and sites where cultural burning has been absent or minimal within the same period.

California Forests and Fire Regimes Preceding Fire Exclusion

Pre-colonial California forests had relatively lower tree densities compared with forests after fire exclusion policies were enacted and timber practices ensued because of repeated low-severity cultural burns, combined with uninhibited wildfire spread (Parsons and DeBenedetti 1979; Scholl and Taylor 2010; Collins et al. 2011; Knapp et al. 2013). Pre-colonial cultural burning created fuel discontinuity, and thereby, reduced both areas and severities of wildfires (Miller et al. 2012; Steel et al. 2015; Taylor et al. 2016). In Karuk and Yurok Indigenous territory, situated in the Klamath and coastal mountains of northwest California, historical pyrodiversity and anthropogenic burning supported considerable landscape heterogeneity and biodiversity (Whittaker 1960; Martin and Sapsis 1992; Skinner et al. 2006). Fire histories reconstructed through dendrochronological methods show that during the era preceding fire exclusion, fire return intervals were significantly shorter when compared with the post-fire exclusion era (e.g., 8.5 years versus 21.8 years; F. Lake and E. Knapp USDA Forest Service unpublished data; Taylor and Skinner 1998; Skinner et al. 2006). Furthermore, USDA Forest Service and CAL FIRE databases indicate that anthropogenic fires were more prevalent during the transition to the fire exclusion paradigm (e.g., 1910 – 1930), than compared with the 1990s and 2000s, substantiating the influence of Indigenous burning in the region (Busam 2006; Miller et al. 2012). A sediment core from a low-elevation regional lake (Fish Lake, 41°14′N, 123°42′W, elevation: 541 m) also exhibited both increased charcoal accumulation rates and oak (*Quercus* spp.) pollen proportions under cool and wet conditions (Crawford et al. 2015). Crawford et al.'s (2015) findings suggest that Indigenous burning in this locale imparted relatively strong effects on species composition compared with solely climatic patterns.

Historical accounts by Karuk and Yurok Indians confirm that low-severity, brief-interval burning of oak woodlands supported their maintenance throughout northwest California (Thompson 1991; Stewart 2002; Long et al. 2016). Yurok author, Lucy Thompson wrote in 1916 that: "the Douglas fir timber…has always encroached on the open prairies and crowded out the other timber; therefore they have continuously burned it" (Thompson 1991: 33). Mamie Offield, a Karuk woman, stated that oak groves were burned each year to kill insect pests and leave "the ground underneath the trees bare and clean…[as] it is easier to pick up the acorns" (Schenck and Gifford 1952: 382). Phoebe Maddux, also Karuk, shared that "the tan oak is not good when it is burned off, the tree dies. When they are burning, they are careful lest the trees burn" (Harrington 1932: 65). Indigenous ecological knowledge of these forest stand dynamics has been transmitted across generations, and persist to date (Lake 2007; Norgaard 2019).

Ethnohistorical accounts have informed land management decisions, and the restoration of low-severity prescribed fire in California forests (Ryan et al. 2013; Stephens et al. 2016; USDA Forest Service PSW Region 2018), however, contentious debates remain. Parker (2002) and Vale (1998, 2002), for example, contest that little physical evidence exists to support the argument that extensive landscape modification was created by anthropogenic burning. They argue that climatic conditions primarily drive fire regimes, and that eliminating fire suppression policies and embracing preservationist (wilderness) land management objectives would sufficiently restore fire regimes (Vale 1998, 2002; Parker 2002). In a similar vein, Baker (2014) contests that the low-intensity fire regimes and the low-tree density (e.g., < 150 trees ha^{-1}), park-like forests land management agencies are attempting to restore, do not accurately reflect historical conditions of California montane forests from General Land Office (GLO) surveys (1865 – 1885) that suggest greater tree densities (e.g., 293 trees ha^{-1}). However, others have suggested that GLO data may over-estimate historical tree densities (Hagmann et al. 2013), and that post-fire exclusion, tree densities have increased compared with those found in GLO surveys (Fulé et al. 2014). Other studies in the Sierra Nevada that compare historical forest stand inventories at smaller-scales show that relatively low tree densities were prevalent preceding fire exclusion, and densities have since increased (Scholl and Taylor 2010; Collins et al. 2011; Stephens et al. 2015). In the southern Klamath mountains, Taylor and Skinner (2003) also found that tree densities increased post-fire exclusion.

Studies of pre-colonial human-fire dynamics, that combine historical and paleo-ecological data with archaeological and human ecological data at relatively fine scales elucidate important nuances in fire regimes and forest stand structure (Lightfoot et al. 2013; Roos et al. 2016, 2019; Swetnam et al. 2016; Taylor et al. 2016; Power et al. 2018; Walsh et al. 2018). Most importantly, if studies incorporate analyses of contemporary restored cultural and prescribed fire regimes that are driven by Indigenous subsistence and cultural objectives, empirical results would inform efforts to reconstruct the effects of Indigenous fire practices on forest and landscape dynamics (Murphy and Bowman 2007; Bliege Bird et al. 2008; Shebitz et al. 2009; Bilbao et al. 2010; Laris 2011; Halpern 2016; Trauernicht et al. 2016; Hart-Fredeluces and Ticktin 2019).

Contemporary Effects of Fire Exclusion

Since the early 20^{th} century (e.g., 1905 – 1920), the policies of the federal and California state government have not only excluded prescribed burns, but have emphasized private-public sector forest management policies and practices that prioritize an extractive commercial timber economy (Clar 1959; Laudenslayer and Darr 1990; Speece 2009). In combination, these policies produced widespread changes in both forest composition and stand structure as well as resulted in an accumulation of understory surface fuels (Parsons and DeBenedetti 1979; Laudenslayer and Darr 1990; Agee 1993).

Since the 1970s, fire areas in the Klamath mountains have grown in area compared with records from 1910 – 1950, as timber plantations composed of small diameter conifers have increased fuel continuity and fire severity, and anthropogenic ignitions have been excluded (Weatherspoon and Skinner 1995; Odion et al. 2004; Miller et al. 2012; Zald and Dunn 2018). Fire exclusion, coupled with timber plantation practices, has also affected the distribution of hardwood tree species (e.g., *Quercus spp.*, *Notholithocarpus densiflorus*, *Umbellaria californica*, and *Arbutus menziesii*; Long et al. 2018). In timber extraction areas, the USDA Forest Service regularly used herbicides since the 1960s to suppress hardwood regeneration and support conifer growth (Strothmann and Roy 1984; Segawa et al. 1997; Harrington and Tappeiner 2009). This practice has imparted negative effects on species such as tanoak (*Notholithocarpus densiflorus*) and California black oak (*Quercus kelloggii*), whose acorns provide the foundation of Indigenous subsistence and livelihood in the region (Tushingham and Bettinger 2013; Long et al. 2016; Norgaard 2019).

Fire exclusion has also facilitated fire-sensitive species, such as Douglas fir (*Pseudotsuga menziesii*), to out-compete hardwood species such as oaks. Douglas fir is able to grow vertically at greater rates than California black oak (*Quercus kelloggii*), and, thus, can replace black oak stand dominance in the absence of fire (Barnhart et al. 1996; Hunter and Barbour 2001; Cocking et al. 2012; Schriver et al. 2018). Douglas fir also develops thick, fire-resistant bark as it matures that effectively protects it from low-intensity fire (Zeibig-Kichas et al. 2016). Hardwoods such as black oak are resilient to fire given their ability to persist after low-intensity burns and re-sprout from the root crown after higher-severity burns (McDonald and Tappeiner 2002; Cocking et al. 2014; Hammett et al. 2017; Nemens et al. 2018; Pawlikowski et al. 2019). Black oak leaf litter is also highly flammable, creating an understory fuel bed that is more conducive to fire compared with Douglas fir stands (Engber et al. 2011; Schwilk and Caprio 2011; Engber and Varner III 2012). Therefore, others have proposed that a low-intensity, brief-interval (e.g., every 3 – 10 years) fire regime could facilitate the maintenance of black oak woodlands throughout its range

(Skinner et al. 2006; Long et al. 2016; Nemens et al. 2018). These dynamics align with the theory of alternative stable states, which predicts that certain ecological communities are maintained through consistent perturbations such as low-intensity fires (Botkin and Sobel 1975; Bond and Van Wilgen 1996; Beisner et al. 2003; Staver et al. 2011). In the absence of these perturbations, oak woodlands in northwest California are predicted to transition to an alternate state dominated by Douglas fir (Huntsinger and McCaffrey 1995; Cocking et al. 2012).

Cultural Fire Resurgence

While there has long been an interest in reversing fire exclusion policies and revitalizing cultural burning in the region, the recent resurgence is often accredited to partnerships with the Nature Conservancy's Fire Learning Network and the initiation of prescribed fire training exchanges (TREX) in 2012 (Terence 2016). TREX burn days are scheduled either weeks or months in advance and recruit qualified wildland fire personnel from different agencies across the nation to conduct burns.

This recent resurgence of prescriptive cultural burning occurring within Karuk and Yurok territory is connected to their communities' efforts to revitalize spiritual and cultural practice (Buckley 2002; Field 2008; Smith 2016; Baldy 2018), as well as the unprecedented fuel hazards generated by fire exclusion policies (Vaillant and Reinhardt 2017). Given that the land base of the Karuk and Yurok Tribes has been significantly circumscribed by federal and private timber and conservation interests (Huntsinger and Diekmann 2010; Norgaard 2019), Tribal members and Tribal governments have been working in partnership with federal agencies and non-governmental organizations to re-integrate fire and Indigenous livelihoods into forest management (Underwood et al. 2003; Levy 2005; Long and Lake 2018).

Cultural burns are almost entirely located on Tribally or privately-owned parcels, although there are some occurring on National Forest lands in partnership with the Forest Service (Colegrove 2014). These cultural burns have multiple objectives, and sites are selected through multiple criteria that may include wildfire protection potential, biophysical conditions during a TREX, and relative ecocultural resource density. For example, many of these sites have been culturally burned with the aims to increase the production of basketry stems from California hazelnut shrubs (*Corylus cornuta* var. *californica*) as well as to reduce fuel loads near homes (Chapter Three). The enhancement of hardwood stands, oak woodlands and savannas with cultural burns are also stated objectives of Tribal members, their organizations, and governments (Huntsinger and Diekmann 2010; Karuk Tribe Department of Natural Resources 2011; Manning and Reed 2019).

The recent application of prescribed burns from 2015 – 2019 provide an outstanding opportunity to directly observe the characteristics of sites being burned. I evaluate how social variables, such as burn type (e.g., TREX or USDA Forest Service) and Tribal territory (i.e., Karuk and Yurok) affect cultural burn frequencies at sites, and I document the biophysical and climatic conditions during cultural burns. Using historical and regional fire ecology as a basis for our inquiry, I assess if cultural burns: 1) reduce surface fuels; and, 2) alter the density of fire-sensitive Douglas fir seedlings and saplings. Then I expand the spatio-temporal scales of my analyses to examine if: 3) overstory tree species composition; and, 4) basal area and tree densities change with cultural fire event frequency as predicted to occur in pre-colonial forest stand structures. Framed by alternative stable states (Botkin and Sobel 1975; Petraitis and Latham 1999; Beisner et al. 2003; Suding and Hobbs 2009; Hughes et al. 2013), I predict that those areas that have only recently been culturally burned after decades of fire exclusion, and those areas that are adjacent to high frequency burned areas, will have transitioned to forest stands that are dominated by fire-sensitive Douglas fir canopies with comparatively high tree densities and basal areas.

METHODS

Study Area

The study area consists of burned and adjacent unburned areas (Fig. 23) within the 1919 km^2 ancestral territory of the Yurok Tribe and the 2728 km^2 ancestral lands of the Karuk Tribe (Fig. 21A; Waterman, 1920, Baumhoff, 1963). Settlements historically were concentrated along the Klamath River and the Pacific coast (Waterman 1920; Kroeber 1936; Bright 1957), and hunting and gathering grounds for critical ecocultural resources were managed and tended by families or individuals (Waterman 1920; Bettinger 2015). Today, the Yurok and Karuk Tribes comprise ~6,000 to ~7,000 members, and are two of the most populous of 109 California Tribes currently ‘recognized’ by the US Federal government (United States Census Bureau 2010b). In Karuk territory, the federal government did not establish a reservation, leaving merely 3.83 km^2 of Karuk trust lands in their ancestral territory, with the remainder largely under the jurisdiction of the Klamath and Six Rivers National Forests and scattered private homesteads (Fig. 21A; Davies and Frank, 1992, Norgaard, 2014, US Census Bureau, 2017). As a result, Karuk Tribal members and management agencies must navigate the USDA Forest Service’s claims on their ancestral territory, and have limited options to expand their land base through the acquisition of private land holdings.

In Yurok territory, multiple overlapping jurisdictions occur including Redwood National Park (192 km^2, Underwood et al., 2003) and Six Rivers National Forest (577 km^2) outside of the reservation established by the federal government. The reservation is located along a 1.6 km buffer following the Klamath River from its estuary to ~80 km upriver (~225 km^2; Huntsinger and Diekmann, 2010). However, 106 km^2 (47%) of the reservation is under private timber company ownership (Yurok GIS Program, 2015). Consequently, the Yurok Tribe must either coordinate or interact with multiple actors within their ancestral territory. However, due to greater proportions of private property in Yurok ancestral territory, the Yurok Tribe presently has more options to acquire private properties when compared with the Karuk Tribe.

Annual precipitation in the study region ranges from 115 – 157 cm (PRISM Climate Group Oregon State University), with strong orographic effects, and ~90% of precipitation occurring between October and April (Skinner et al. 2006). Lightning-ignited fires are more common at higher (e.g., 600 – 1,799 m asl) elevations and generate mixed severities with strong topographic effects (Skinner et al. 2006; van Wagtendonk and Cayan 2008; Halofsky et al. 2011).

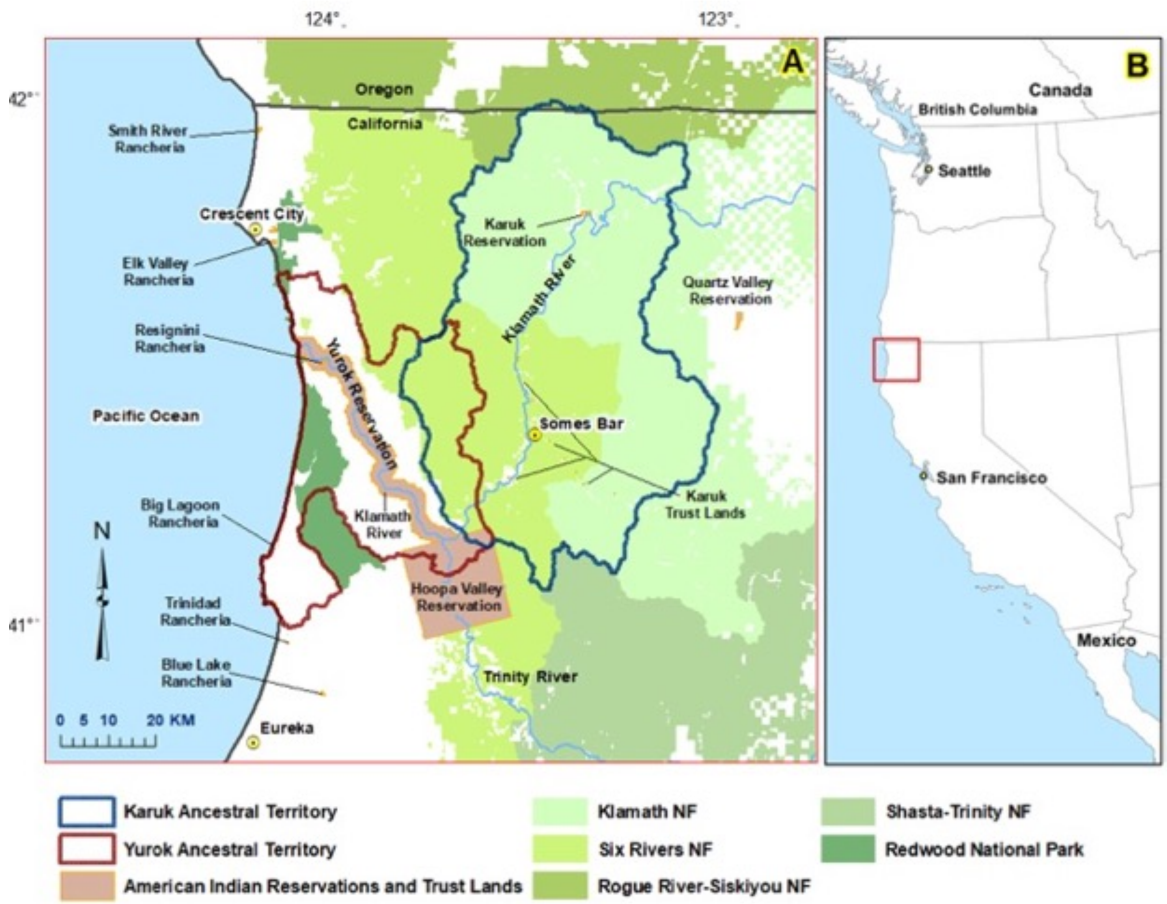

Figure 21. (A) Study Region with Federal Jurisdictional Boundaries and Karuk and Yurok Territories. Ancestral territory boundaries, provided by the Karuk and Yurok Tribes, represent reconstructions, but currently are not fixed or rigid boundaries. Ancestral lands of other Northwest California Tribes (e.g., Tolowa, Wiyot, Hupa, Shasta) are not included here, but note that their ancestral lands may partially overlap with the boundaries rendered here (Baumhoff, 1963). **(B) Western Region of the United States of America.** The study region is depicted by the red box.

Fire Ecology and Forest Stand Surveys and Analysis

I tracked 30-year (1989 – 2019) fire histories in Karuk and Yurok territories within 45 cultural and prescriptive burn sites burned from 2014 to 2019 on the Klamath and Six Rivers National Forest as well as on privately and Tribally-owned properties (Fig. 23). Site burn histories were reconstructed by conferring with the California Department of Forestry and Fire Protection's prescribed fire GIS database (https://frap.fire.ca.gov/mapping/gis-data/), and through interviews with property owners, care-takers, and fire managers. Burn frequencies were recorded and then divided into either 'low' (< 3 burn events) or 'high' frequency (≥ 3 burn events) from 1989 - 2019. Three or more burn events were deemed 'high' frequency because three burns over a 30-year period could produce a fire return interval of ~10 or fewer years, which approximates fire return intervals in local pre-fire exclusion dendrochronologies (F. Lake and E. Knapp, unpublished USDA Forest Service data). In addition, owners and managers who burned properties at high frequency typically did not know the exact number of burns, but could say that they burned ≥ 3 times, or, for example, 'approximately every 5 years for the past 30 years'.

From January 2015 to March 2019, I established and monitored 48 plots (20 x 20 m, 400 m^2) within 21 cultural and prescriptive burn sites along with 12 paired unburned areas. The mean elevation of the plots was 343 m (a.s.l.). Plots were randomly placed within potential burn sites with varying fire histories identified by fire managers and property owners. Within these plots, I measured the diameter at breast height of all overstory trees ≥ 10 cm, along with the tree species. Basal area and tree density by species (m^2 ha^{-1} of trees ≥ 10 cm dbh) was calculated for each plot, the tree species with the greatest relative percentage of basal area was recorded as the dominant overstory tree, and then subdivided into either 'hardwood' or 'conifer' tree classes. In a sub-sample of 13 plots, I measured Douglas fir seedlings (< 1.37 m height) and saplings (< 10 cm dbh) within eight months before and between 11 and 20 months following either a prescribed or cultural burn. Tree mortality and char height were also measured in this post-burn period.

Wilcoxon rank sum tests were performed to evaluate the relationship between burn frequency (as a continuous variable) and dominant overstory tree species class (hardwood vs. conifer), as well as burn frequency and territory (Karuk vs. Yurok). A t-test was performed to assess differences in tree density between high and low frequency burn sites, and a paired Wilcoxon rank sum test was performed to evaluate the effects of prescribed and cultural burns on living Douglas fir seedling and sapling densities pre- and post-burn.

To identify potential explanatory variables that affected overstory tree basal area, gamma generalized linear models (GLM) were developed in R (R Core Team 2014), and burn frequency, dominant overstory tree species, and Yurok or Karuk indigenous territory (Figure 1) were set as explanatory variables. Type II Wald Chi Square tests were used to perform backward model selection using the 'car' package in R (Fox and Weisberg 2018). The sjPlot package (Lüdecke 2019) was applied to analyze and visualize the effects of significant variables in the GLM.

Based upon my observations and those recorded by fire managers, I collated 10-h fuel moistures (%), relative humidity (%), temperature (°C), and wind speed (km/hr) from 30 cultural and prescribed burns. Fuel moisture (%) was measured by collecting 10-h woody fuels from the burn area, measuring their wet mass, and then dry mass after fuels were dried in a convection oven for 24 hours at 80 °C. Relative humidity, temperature, and wind speed were measured using a mobile weather meter (e.g., Kestrel 3000) or a sling psychrometer.

In a sub-sample of 27 plots, I randomly sampled three 10 m planar transects pre- and post-burn to evaluate the potential effects of these burns on fuel loads. Using methods derived from Brown (1974), I counted intersecting woody dead and down fuels, including 1-h fuels (<6 mm) and 10-h fuels (6 – 25 mm; 0.00-1.86 m); 100-h fuels (>25 – 76 mm; 0.00-3.05 m; and I measured the diameters of solid and rotten 1000-h fuels (>76 mm; 0-10 m). Litter and duff depths were also recorded at both 1.86 m and 3.05 m. These woody fuel measurements were converted to Mg ha^{-1} using formulas from Brown (1974), and litter and duff depths were converted to Mg ha^{-1} using coefficients from Van Wagtendonk et al. (1998). I compared fuel loading pre- and post-burn across all size classes with Wilcoxon rank sum tests.

Geospatial Analyses of Deciduous Tree Cover

To scale-up my analysis of dominant overstory tree species from the 400 m^2 monitoring plots, I used remotely sensed images to analyze the effects of cultural burn frequency on deciduous tree cover (i.e., California black oak) across entire burn areas that contained plots. I acquired two remotely sensed images from August 11, 2018 and two images from March 15, 2019, each taken at 3 m^2 resolution with four bands (including red and near-infrared) from the eastern region of the Yurok ancestral territory (long/lat: 41.200000, -123.700000). These four images were obtained from PlanetScope satellites (Planet Labs, Inc., San Francisco, California; planet.com). The Normalized Difference Vegetation Index (NDVI) is a measure of live green vegetation (range: -1.0 to 1.0) generated from the near-infrared (NIR) and red (RED) spectral reflectance of vegetation [NDVI = (NIR – RED)/(NIR + RED)] (Pettorelli et al. 2005). NDVI was calculated for each 3 m^2 pixel in every image using ENVI software (version 5.4, Harris Geospatial Solutions, Inc., Bloomfield, Colorado). Deciduous canopies display relatively high NDVI values in August and, correspondingly low NDVI values in March. In contrast, evergreen coniferous canopies display high NDVI values year round. To identify areas of deciduous tree cover, NDVI values from January were subtracted from the overlapping July NDVI values across a 305 km^2 area using the Band Math function in ENVI.

Using Arc Map 10.6 (ESRI, Inc., Redlands, California), I superimposed the burn perimeters of seven areas known to have burned ≥ 3 times (from 1989 - 2019) over the image with NDVI change values (Δ NDVI). Based upon the mean burn area (10.1 ± 5.0 ha), I created seven circular areas of 10.1 ha within areas known to have experienced < 3 burn events from 1989 to 2019 (Fig. 25). These circular plots were placed either in areas adjacent to high frequency burn areas known either to have been unburned or were placed in proposed or low frequency burn areas containing individual black oak specimens. Within each burn perimeter and circular area, mean Δ NDVI was measured within ten randomly-distributed samples of 500 m^2 using the 'Create Random Points' and 'Buffer' tools in Arc GIS. Then, Δ NDVI between areas that experienced ≥3 burn events and <3 burn events were compared using a Wilcoxon rank sum test.

RESULTS

From 2015 to 2019, 64 prescribed broadcast burns occurred within Karuk and Yurok territories. An area of at least 552 ha was burned through prescribed fire training exchanges (TREX) while 13 prescribed burns (712 ha combined) were conducted by the USDA Forest Service (Table 4, Fig. 23). Yurok territory sites (n = 13) were burned at significantly higher frequencies between 1989 and 2019 (μ = 3.00 burn events, SE = 0.57) compared with burn sites within Karuk territory (n = 32, μ =1.34 burn events, SE = 0.13, $p < 0.001$, Fig. 26). The majority (75%) of these burns were conducted in the fall (September 21 – December 21). However, burns were also conducted when conditions were suitable in other seasons. In Yurok territory, 12 burns (17% of all burns) occurred in the winter (December 22 – March 21), all within sites with overstories dominated by black oak. Of the four spring burns (6% of total, March 22 – June 21), three were conducted by the USDA Forest Service within Karuk territory.

During the burns, the mean 10-h fuel moisture level was 18% ± 2% (range: 9 – 67%), mean minimum and maximum relative humidity spanned 35% to 50%, ambient temperatures ranged from 18 - 24 °C, with all wind speeds below 13 km hr^{-1} (Table 5). USDA Forest Service burns occurred when fuel moistures were drier ($\bar{x}$ = 12.4, $\sigma_{\bar{x}}$ = 1.7) than during TREX burns ($\bar{x}$ = 21.5, $\sigma_{\bar{x}}$ =3.5), but they were not significantly different (p = 0.058, Table 5). Burn fuel moistures by season also showed no significant differences. Burning techniques and thus flame lengths varied depending upon site conditions. However, strip-ignition backing fires were typically used in hardwood understories with the majority of flame lengths < 1 m.

Prescribed and cultural burns significantly reduced litter, duff, 1-h and 10-h fuels ($p < 0.001$), but not 100-h or 1000-h fuels (Table 6). Moreover, prescribed and cultural burning significantly reduced Douglas fir understory regeneration in seedlings (≤ 1.37 m height) and saplings (< 10 cm dbh) from a pre-burn mean of 272,000 (± 109,000) ha^{-1} seedlings and saplings to post-burn survivorship of only 54,000 (± 23,000) ha^{-1} seedlings and saplings ($p < 0.01$). Black oak trees (≥ 10 cm dbh) that were killed within 1-year post-burn (2% of all burned trees sampled, n = 172) had been burned in the fall or summer months (July – October, n = 56).

Field and geospatial analyses show that relatively high frequency cultural burning practices ($\geq$ 3 burn events/site between 1989-2019) facilitate hardwood tree overstories (p < 0.001, Figs. 22, 24 and 25, Table 7) predominantly composed of deciduous California black oak. Black oak dominated 68% of hardwood overstories (n = 28), and, on average, ~50% of the overstory tree basal area at high frequency burn sites, with the remainder composed of other hardwoods (30%) and Douglas fir (19%, Table 7). In contrast, overstory tree basal area at low frequency burn sites (< 3 burn events/site between 1989-2019) were, on average, comprised of 70% Douglas fir and 25% hardwood species (Fig. 22, Table 7). Seasonal changes in NDVI from summer (August) to winter (March) within high and low frequency burn sites corroborated these field analyses. Change (Δ) in NDVI was 1.8-fold greater within sites that experienced $\geq$ 3 burn events ($\mu = 0.33 \pm 0.016$) compared with sites that experienced < 3 burn events ($\mu = 0.18 \pm 0.009$, $p < 0.0001$, Fig. 25).

Total overstory tree basal area ($m^2\ ha^{-1}$; trees $\geq$ 10 cm dbh) surveyed in high frequency burn plots (n = 26) was < 50% (Marginal $\bar{x} = 31.1\ m^2\ ha^{-1}$, $\sigma_{\bar{x}} = 6.2$) compared with low frequency burn plots (n = 22, Marginal $\bar{x} = 62.6\ m^2\ ha^{-1}$, $\sigma_{\bar{x}} = 2.82$, $p < 0.0001$), and displays a strong negative relationship with burn frequency (as a continuous variable) in the univariate gamma glm model ($p = 0.002$, Fig. 27). Overstory tree basal area in coniferous dominated plots (n = 20) was 1.85-fold greater (Marginal $\bar{x} = 62.2\ m^2\ ha^{-1}$, $\sigma_{\bar{x}} = 6.9$) than in plots dominated by hardwoods (Marginal $\bar{x} = 33.7\ m^2\ ha^{-1}$, $\sigma_{\bar{x}} = 3.2$, $p < 0.0001$). Overstory tree densities were 1.5-fold greater at low frequency burn sites ($\bar{x} = 397.7$, $\sigma_{\bar{x}} = 34.4$) compared with high frequency burn sites ($\bar{x} = 261.5$, $\sigma_{\bar{x}} = 30.5$, $p < 0.01$, Table 7).

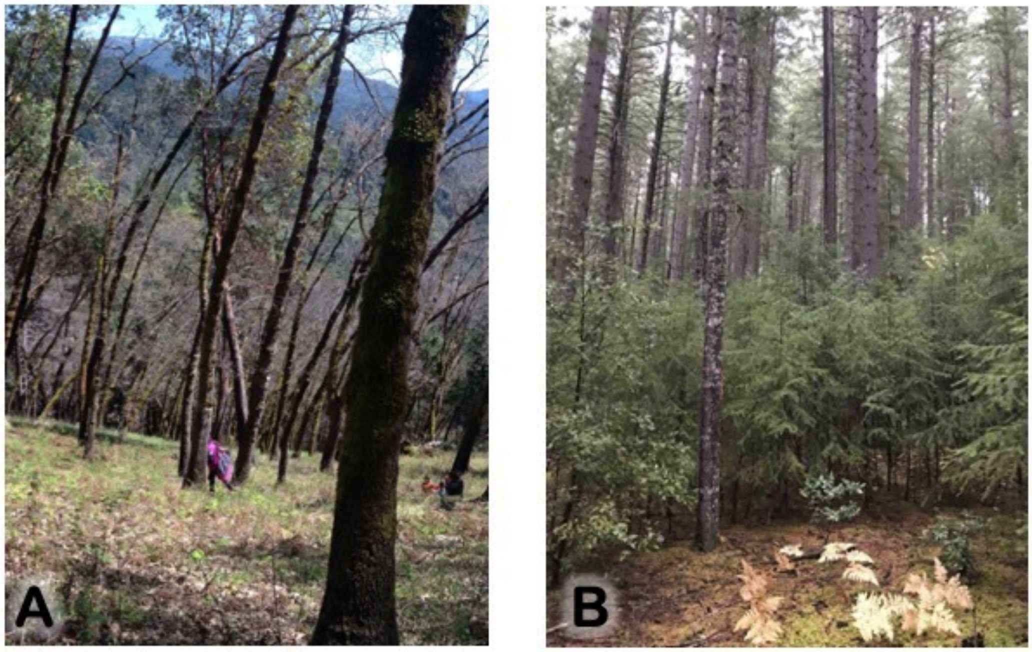

Figure 22 Contrasting Forest Stand Qualities of Cultural Burn Areas. (A) Repeatedly burned (> 3 burn events in 30 years) black oak (Quercus kelloggii) woodland with relatively low basal area and basketry material gatherers in spring. (B) Douglas fir (Pseudotsuga menziesii) dominated stand with Douglas fir saplings in the understory burned < 3 times in the past 30 years.

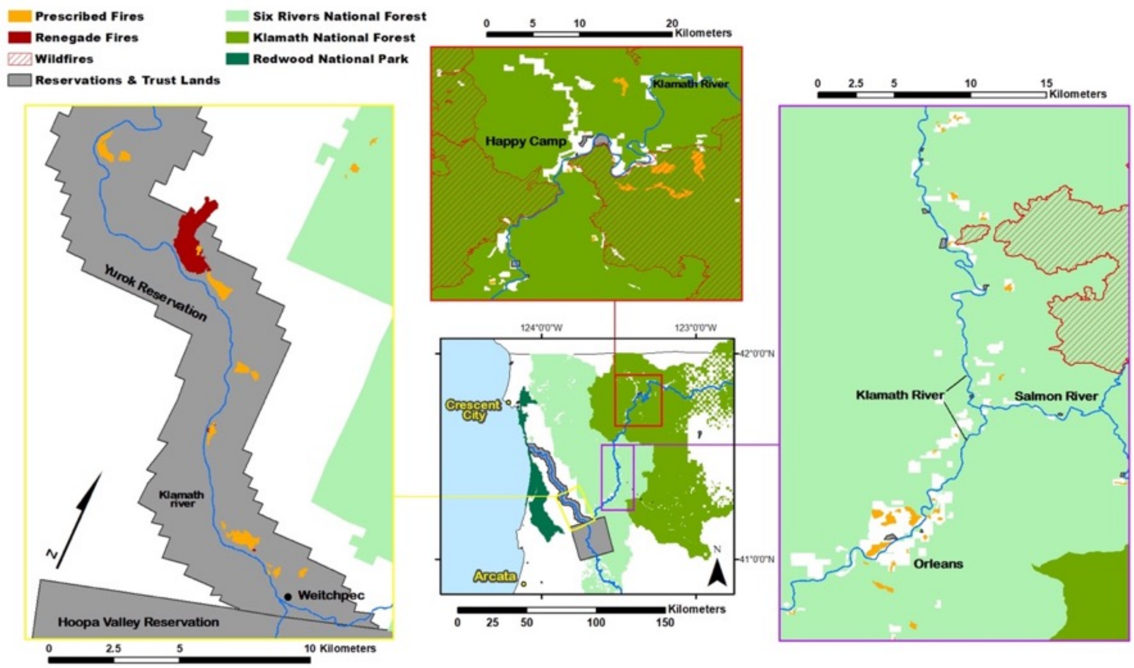

Figure 23. Wildfires with Prescribed and Cultural Burn Fires (2014-2019) within Karuk and Yurok Territory. Prescribed fires were set either by the USDA Forest Service (712 ha, *n* = 8) or through Prescribed Fire Training Exchanges (552 ha, *n* = 54) led by Karuk and Yurok Tribal members in collaboration with local non-governmental organizations and government agencies. Wildfires were initiated either by lightning or other unknown causes.

Table 4. Cultural and Prescribed Broadcast Burn Area from 2015 – 2019 in Karuk and Yurok Territory by Burn Program Management. Burns were conducted by the USDA Forest Service (USFS) and through the Prescribed Fire Training Exchange (TREX) led by Karuk and Yurok Tribal members in collaboration with non-governmental agencies, the USFS, Cal Fire, and others.

Territory	USFS			TREX		
	n	Σ Ha	x̄ Ha	*n*	Σ Ha	x̄ Ha
Karuk	13	712.0	59.0	38	341.0	9.0
Yurok	2	17.0	8.5	26	211.0	8.8

Table 5 Cultural and Prescribed Burn Areas Monitored from 2015-2019 with Weather Conditions. Prescribed Fire Training Exchange (TREX) burns occurred on Tribal and private lands and were led by Tribes and Fire Councils (n = 21) and USDA Forest Service (USFS) burns occurred on National Forest lands (n = 9). Standard errors (±) are in parenthesis, different letters denote significant differences using a t-test ($p < 0.05$).

Burn Type	Area (ha)	10-h Fuel Moisture (%)	Relative Humidity Range (%)	Temperature (°C)	Max Wind Speed (km/hr)
TREX (n=21)	6.98 (2.21)	20.1 (3.2)[a]	35 – 48	18 - 24	13
USFS (n=9)	12.62 (8.02)	12.4 (1.7)[b]	35 – 54	18 - 22	10
Combined Mean	8.45 (2.73)	17.8 (2.3)	35 – 50	18 - 23	13

Table 6. Fuel Loads in Cultural and Prescribed Burn Areas Pre- and Post-Burn. One hour fuels (<6 mm), 10-h fuels (6 – 25 mm), 100-h fuels (> 25 – 76 mm), solid (s) and rotten (r) 1000-h fuels (>76 mm), and litter and duff depths were systematically collected along three 10 m planar transects located randomly within 27 plots (400 m^2). Woody fuel measurements were converted to Mg ha^{-1} using formulas in Brown (1974). Using coefficients from Van Wagtendonk et al. (1998), litter and duff depths were converted to Mg ha^{-1}. Wilcoxon Rank Sum tests were performed to evaluate fuel loading differences pre- and post-burn.

Pre/Post Burn	Litter Mg ha^{-1}	Duff Mg ha^{-1}	1-h Mg ha^{-1}	10-h Mg ha^{-1}	100-h Mg ha^{-1}	1000-h (s) Mg ha^{-1}	1000-h (r) Mg ha^{-1}
Pre-	2.41 (0.24)	2.57 (0.33)	0.73 (0.14)	2.56 (0.33)	2.22 (0.35)	4.31 (1.28)	1.93 (1.63)
Post-	0.27 (0.40)	0.66 (0.19)	0.23 (0.04)	1.25 (0.15)	2.33 (0.51)	3.59 (0.90)	0.32 (0.14)
p	**<0.0001**	**<0.0001**	**< 0.0001**	**<0.001**	0.45	0.50	0.83

Table 7. Mean Overstory Tree Basal Area and Tree Density in High (≥3 Burn Events) Contrasted with Low (<3 Burn Events) Frequency Burn Areas (1989 – 2019).
Overstory tree basal area and tree density of trees ≥10 cm dbh were measured in forty-eight 400 m^2 plots. Standard errors are in parenthesis. DF = Douglas fir (*Pseudotsuga menziesii*); BO = California black oak (*Quercus kellioggii*); MAD = Pacific Madrone (*Arbutus menziesii*); BAY = California bay laurel (*Umbellularia californica*); PP = Ponderosa pine (*Pinus ponderosa*). Other trees include Oregon white oak (*Quercus garryana*), big leaf maple (*Acer macrophyllum*), tanoak (*Notholithocarpus densiflorus*), Pacific dogwood (*Cornus nuttallii*), canyon live oak (*Quercus chrysolepis*), and giant chinquapin (*Chrysolepsis chrsophylla*). Basal area and tree density of BO and DF in high and low frequency burn areas were significantly different using a Wilcoxon rank sum test ($p < 0.05$) and are presented in bold.

	DF	**BO**	**MAD**	**BAY**	**PP**	**Other**	**Total**
Basal Area (m^2 ha^{-1})	**5.942**	**15.199**	7.570	1.253	0	0.948	30.911
≥3 Burn Events	**(1.869)**	**(2.192)**	(2.462)	(0.891)	(0)	(0.370)	(3.042)
Basal Area (m^2 ha^{-1})	**43.144**	**8.114**	4.722	0.884	3.251	1.575	61.690
<3 Burn Events	**(6.664)**	**(2.334)**	(2.262)	(0.760)	(1.771)	(0.634)	(5.651)
Tree Density (ha^{-1})	**33.654**	**142.308**	44.231	23.077	0	18.269	261.538
≥3 Burn Events	**(9.701)**	**(23.195)**	(11.710)	(12.704)	(0)	(7.790)	(30.484)
Tree Density (ha^{-1})	**197.72**	**52.273**	47.727	13.636	43.182	43.182	397.727
<3 Burn Events	**(27.618)**	**(17.322)**	(13.851)	(7.306)	(29.295)	(13.681)	(34.422)

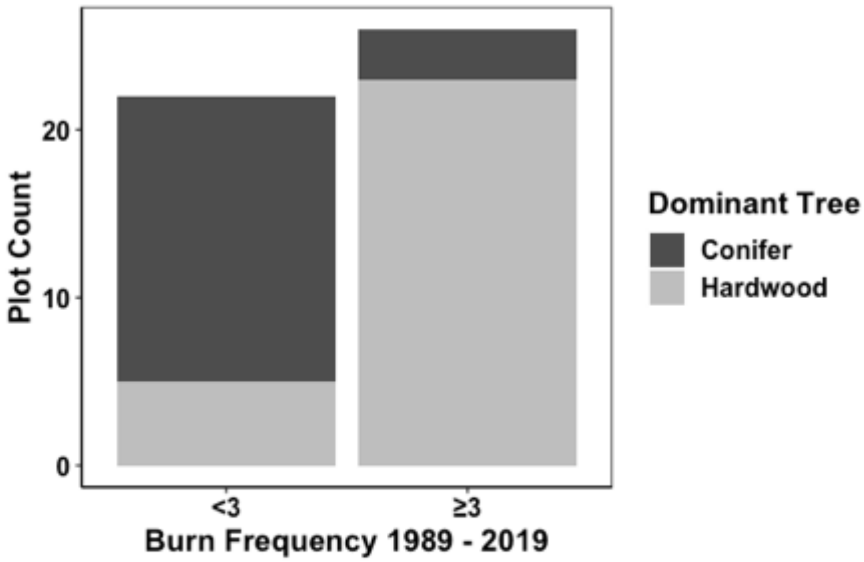

Figure 24. Burn Frequency Effects on Dominant Overstory Conifer and Hardwood Tree Basal Area. Dominant overstory trees (≥10 cm dbh) were determined by relative basal area (m^2 ha^{-1}) within 400 m^2 plots (n = 48). Ponderosa pine (Pinus ponderosa) and Douglas fir (Pseudotsuga menziesii) were classed as conifers, and Black oak (Quercus kellioggii), Madrone (Arbutus menziesii) and California Bay (Umbellularia californica) were classed as hardwoods. Hardwood overstories (n = 28) were more frequent at sites burned ≥ 3 times from 1989 to 2019 compared with coniferous overstories (n = 20) that were more frequent at sites with < 3 burn events ($p < 0.001$). Burn frequencies were determined from several sources, including the California Department of Forestry and Fire Protection's prescribed fire GIS database (https://frap.fire.ca.gov/mapping/gis-data/) coupled with interviews with property owners and fire managers.

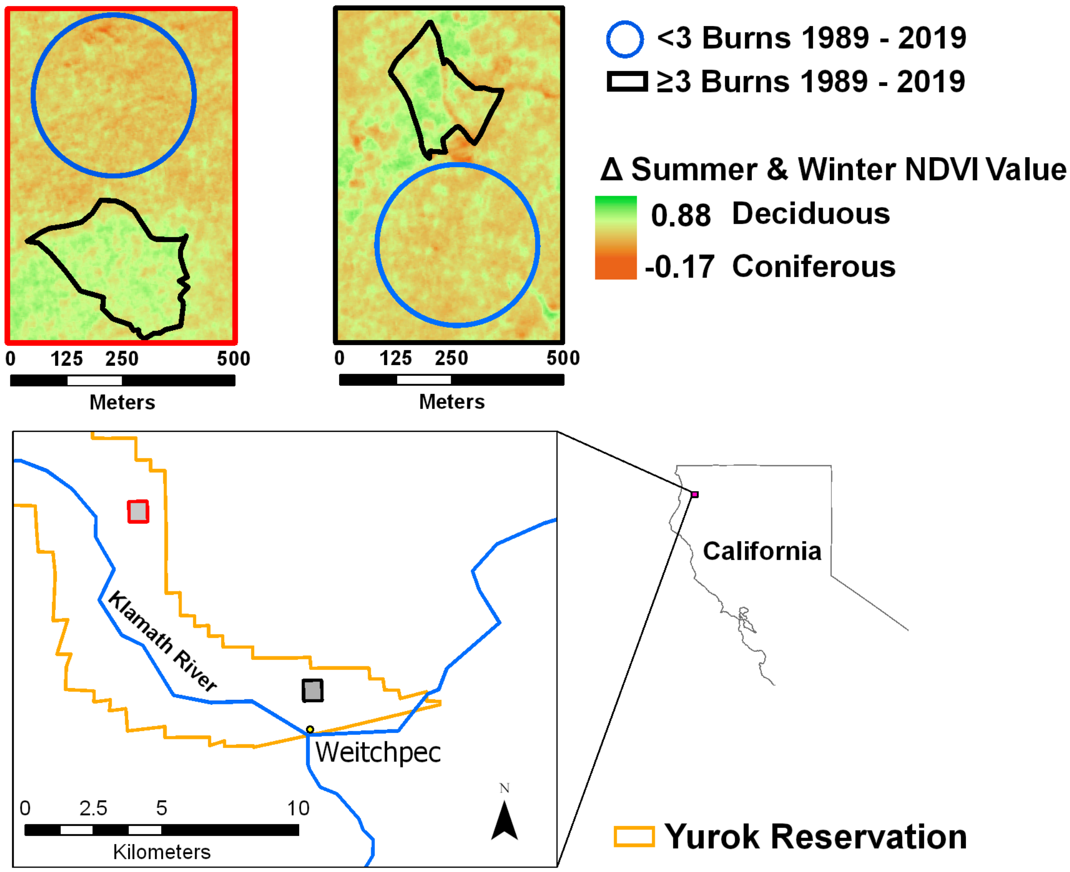

Figure 25. Change in Summer to Winter NDVI at Sites with Contrasting Burn Frequencies Over Thirty Years (1989 – 2019). Box insets display and contrast two of the seven analyzed cultural burn sites (black perimeters) with ≥ 3 burn events from 1989 to 2019. The adjacent blue 10.1 ha sites (mean area of cultural burn sites) are two of the seven matched pair sites that incurred fewer than three burn events from 1989 to 2019. These insets are a subset of a larger area (305 km^2) that was remotely sensed at 3 m^2 resolution by a 4-band Planet Scope satellite in August 2018 and March 2019 (Planet Labs, Inc., San Francisco, California; planet.com). The NDVI from the March image was subtracted from the NDVI on the August image to generate the Δ NDVI. Given that NDVI is a measure of live, green vegetation, deciduous overstories are expected to generate a greater Δ NDVI compared to evergreen coniferous overstories as they have lost their leaves by March. Pixels with a larger Δ NDVI are depicted in green, and those with a lower Δ NDVI are depicted from orange to red. In each of the 14 sites, Δ NDVI was sampled within ten randomly placed 500 m^2 areas. Across all samples, sites with ≥ 3 burn events mean Δ NDVI was significantly greater ($\mu = 0.33 \pm 0.016$) than mean Δ NDVI in sites with < 3 burn events ($\mu = 0.18 \pm 0.009$; $p < 0.0001$).

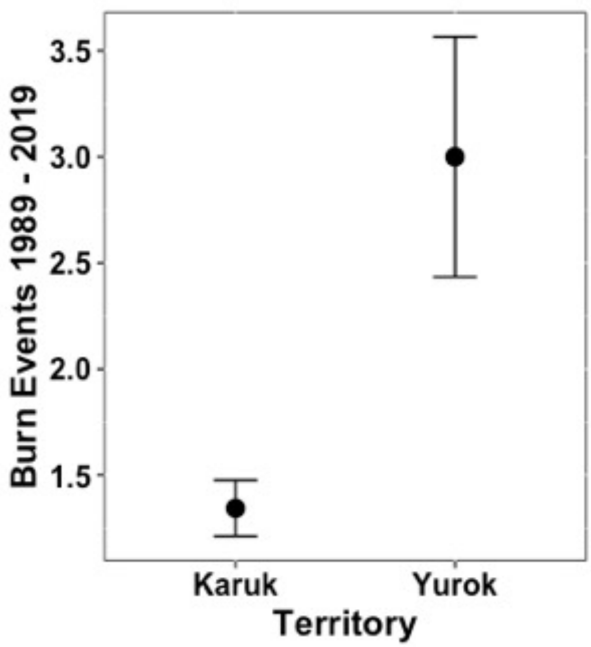

Figure 27. Mean Burn Events (± 95% CI) Contrasted within Karuk and Yurok Indigenous Territories. Of the 45 sites burned from 2015 to 2019, sites in Yurok territory had significantly greater frequency of burn events compared with sites located within Karuk territory ($p < 0.001$).

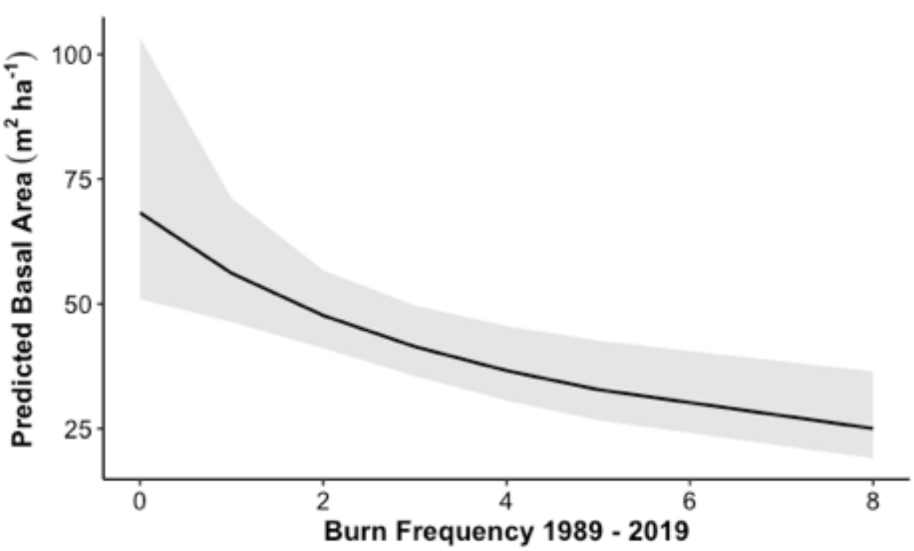

Figure 26. Burn Frequency (1989 -2019) Effects on Overstory Tree Basal Area ($m^{-2}\cdot ha^{-1}$; trees ≥10 cm dbh). Predicted basal area values are based upon a univariate gamma generalized linear model where burn frequency is a significant variable ($p = 0.002$).

DISCUSSION

Forest Stand Dynamics with Fire Management Implications

Repeated burning of hardwood stands in Karuk and Yurok territory can maintain the overstory dominance of trees like California black oak and prevent transitions to forests dominated by Douglas fir. Cultural burning also reduces overstory tree basal area, tree densities, and surface fuels, improving access to Tribal ecocultural resources like acorns and basketry materials found in the understory (Long et al. 2016). Karuk and Yurok people recognize that the high frequency, low-intensity cultural burning documented here is a practical means to facilitate black oak stands and to decrease basal area to enhance their movement and enhance visibility for hunting and gathering across the landscape (Senos et al. 2006; Lake 2007). Expanding cultural burning will thus increase landscape heterogeneity, supporting species diversity and thus Tribal livelihoods.

The Douglas fir dominated stands we surveyed only recently (< 15 years) experienced prescriptive or cultural burning. These stands retained some hardwoods, yet Douglas fir dominated with 70% of the overstory basal area, similar to other encroached oak woodlands in the Pacific northwest (Barnhart et al. 1996; Thysell and Carey 2001; Engber et al. 2011; Cocking et al. 2012; Devine and Harrington 2013). Douglas fir tree densities in the fire excluded sites (197.72 ± 27.62 ha^{-1}) were comparable to other Douglas fir dominated stands in the region (180 ha^{-1}) reported from Taylor and Skinner (2003), although comparatively less than the 577 ± 46.50 ha^{-1} tree densities documented in Karuk territory by Cocking et al. (2012). However, the tree species basal area documented across these sites (e.g., Douglas fir: 43.14 ± 6.66 m^2 ha^{-1}; Black oak: 8.11 ± 2.33 m^2 ha^{-1}) were similar to those found by Cocking et al. (2012) at an encroached black oak site in Karuk territory (e.g., Douglas fir: 38.01 ± 3.26 m^2 ha^{-1}; Black oak: 11.78 ± 1.05 m^2 ha^{-1}). Although the methods employed were different, the total overstory basal area of high frequency burn sites dominated by black oak and other hardwoods (30.91 ± 3.04 m^2 ha^{-1}) were similar to the overstory basal area of pre-fire exclusion Sierra Nevada mixed-conifer sites (29.9 m^2 ha^{-1}, SD 19.6, Scholl and Taylor 2010; and 24.6 ± 5.7 m^2 ha^{-1}, Stephens et al. 2015).

In this region, fire managers typically conduct prescriptive burns when 10-h fuel moistures range from 8% to 15% (Biswell 1999), yet the TREX burns we documented had an average 21% fuel moisture. Thus, some burn events had limited fire intensity, patchy fuel consumption, and minimal Douglas fir seedling/sapling mortality. One of TREX's key objectives is to create training opportunities for fire professionals and community members. Because dates for TREX are set months in advance, weather during these exchanges is unpredictable. Nonetheless, TREX currently provides one of the few effective mechanisms for galvanizing sufficient resources to conduct burns. As a result of TREX and Fire Learning Network support, the Karuk Tribe and the Orleans/Somes Bar Fire Safe Council partnered to create a year-round wildland fire team beginning in 2019 that will be ready to burn during ideal weather conditions as they arise. Thus, they are expected to increase opportunities to expand cultural burning frequency and area.

On the Yurok reservation the Tribe and Tribal members have maintained land tenure over the past three decades, which has enabled some sites to be burned at high frequency. TREX conducted on the Yurok reservation by the Cultural Fire Management Council developed a winter/spring season TREX event with a roving burn date dependent upon weather that has increased their capacity to burn, especially within black oak woodlands. Because black oak is deciduous, comparatively high sun exposure during the winter months (December - March) often creates opportunities for highly flammable black oak leaves to dry and successfully burn (Engber and Varner III 2012; Long et al. 2016). These early season burns also have a reduced risk of escaping than burns set in fall months (September – November), as nearby coniferous or prairie habitats retain more moisture and serve as natural firebreaks in the winter.

Because the USDA Forest Service has access to personnel across an extended fire period than TREX does, they theoretically have greater flexibility to burn on National forest lands when conditions are ideal. However, USDA Forest Service fire managers often cannot burn under these conditions because of bureaucratic constraints limiting access to personnel (Quinn-Davidson and Varner 2012; Schultz et al. 2018; Chapter 6). To overcome these obstacles, discussions are underway to develop partnerships between National Forests and the Karuk Tribe wildland fire team to provide additional personnel for the USDA Forest Service when they are under-staffed. These partnerships have the potential to expand the necessary burning and thinning that can restore hardwood forests and their socio-economic benefits to California Indians.

Reintroducing prescribed fire into oak woodlands invaded by Douglas fir is complex and challenging because Douglas fir stands become increasingly fire resilient as they mature. As Douglas fir individuals mature, they develop thicker bark (Zeibig-Kichas et al. 2016), and their compact needles have reduced flammability compared with other species (Schwilk and Caprio 2011). In our study region, Odion et al. (2004) found that closed canopy forests dominated by Douglas fir promoted lower fire severities because of these and other stand characteristics. As a result, fires did not cause a transition to a pyrogenic hardwood or shrubland ecosystem, but, instead, maintained Douglas fir forests. Therefore, once a black oak woodland transitions to Douglas fir dominated stands, it appears to fit a hysteretic alternative stable state, as the restoration of a low intensity anthropogenic fire regime alone will not create conditions that would facilitate a return to a black oak stand (Scheffer and Carpenter 2003; Suding and Hobbs 2009). Removing Douglas fir from encroached black oak stands may be necessary to re-establish black oak stands and forest landscape mosaics with associated heterogeneity (Cocking et al. 2012).

However, the transition from black oak to Douglas fir in the absence of fire is relatively slow (e.g., 50 - 75 years; Cocking et al. 2012, Schriver et al. 2018) and is not marked by a rapid and irreversible threshold (Hughes et al. 2013). While Douglas fir growth is comparatively rapid in comparison with black oak growth, land managers can identify stands where the transition is occurring and employ actions to facilitate this transition. Cutting and girdling can eliminate Douglas fir, and then be followed by a short-interval (every 3 – 5 years) burning regime. In *Quercus garryana* stands in Washington State, the removal of Douglas fir overstory trees improved acorn production and oak growth (Devine and Harrington 2013).

Black oak stands in transition to Douglas fir that experience high severity wildfire may also be a pathway to black oak restoration. Black oak re-sprouting readily occurs post-wildfire and in successive wildfires (Cocking et al. 2014; Hammett et al. 2017; Pawlikowski et al. 2019). However, Nemens et al. (2018) suggest that repeated high severity fire events may not lead to the development of a mature black oak woodland, while Cocking et al. (2012) found that Douglas fir encroachment can increase the probability of black oak mortality in a wildfire. The unpredictability and varying severities of wildfire make reliance on wildfire events an unreliable management mechanism for maintaining black oak stands. However, after a high severity fire event that leads to Douglas fir mortality and black oak resprouting, our data shows that repeated low intensity burning can maintain black oak dominance. Furthermore, as we found in mature black oak stands in the Klamath mountains, low-intensity burning of mature *Quercus garryana* stands in Washington and Oregon has been documented to maintain oak dominance (Tveten and Fonda 1999; Hamman et al. 2011), and has resulted in minimal *Quercus garryana* overstory mortality (Nemens et al. 2019).

Cultural Burning and Alternative State Forest Stand Dynamics

Our interpretation of oak-fir alternative stable state dynamics identifies Indigenous cultural fire practices as the central positive-feedback mechanisms that maintains oak woodlands, and embeds this system within a socio-ecological framework (Walker et al. 2004; Liu et al. 2007). This system contrasts from studies that analyze anthropogenic fire as a negative perturbation that causes forests to transition to shrub or grasslands (Perry and Enright 2002; Kitzberger et al. 2012; Innes et al. 2013; Paritsis et al. 2015). While these dynamics are pervasive in regions where timber and agricultural commodity markets are expanding (Cochrane et al. 1999; Carlson et al. 2012), Indigenous fire regimes do not result in large-scale or high percentage forest canopy cover reductions (Russell-Smith and Cook 2013; Welch et al. 2013). Indigenous burning typically is relatively low intensity when compared with anthropogenic burning for agricultural clearing.

In Australia, an analysis of fire intensity found that Aboriginal low-intensity patch burning of a fire-sensitive conifer encouraged its persistence compared to a high-intensity wildfire regime from primarily lightning ignitions and the absence of Indigenous burning (Trauernicht et al. 2016). Trauernicht et al. (2016) highlight the importance of low intensity anthropogenic burning to maintain forest stands in areas where high severity fires occur. In California, Anderson (2018) suggests that Indigenous burning adheres to the intermediate disturbance hypothesis, and promotes the greatest species richness (i.e. β diversity; Perry et al. 2011). Although intensity is not included in Anderson's conceptualization, low intensity burning may be conceived as an intermediate disturbance across a spectrum of fire intensity spanning from fire exclusion to high intensity wildfire. This intermediate fire intensity appears to be highly suitable for the enduring subsistence needs of California Indians.

California Indian reliance upon acorns for subsistence (Basgall 1987; McCarthy 1993; Tushingham and Bettinger 2013), and other ecocultural species that thrive in the understory of oak woodlands (e.g., California hazelnut; Chapter 4) favored the construction of an oak woodland ecological niche. Therefore, repeated low-intensity burning and other management activities were mechanisms for maintaining black oak stands and inhibiting the transition to a Douglas fir alternative stable state (Huntsinger and McCaffrey 1995; Hunter and Barbour 2001; Cocking et al. 2012). This mutualistic oak-human relationship likely contributed to a highly heterogeneous patch mosaic landscape that created co-evolutionary relationships amongst many species (Lightfoot and Parrish 2009; Bliege Bird et al. 2013; Lightfoot et al. 2013; Codding et al. 2014; Long et al. 2016).

The status of oaks as cultural keystone species (Garibaldi and Turner 2004; Platten and Henfrey 2009) generated a burning regime in California associated with their intentional, long-term management and imparted epiphenomenal effects on other species including wildlife (e.g., birds, rodents, and deer; Long et al. 2016). In Australia, Codding et al. (2014) found that the positive relationships between Martu Aboriginal burning and fauna abundance (e.g., Kangaroo and lizards) were not the result of intentional management, but that the fine-grained habitat heterogeneity that benefits wildlife is an emergent property derived from hunting objectives achieved through burning. In California, subsistence practices also provide the source of habitat heterogeneity and pyrodiversity throughout this biome (Martin and Sapsis 1992; Lightfoot and Parrish 2009). However, the life history of oaks contrast considerably with the fauna that form a major component of the Martu diet (Bird et al. 2009). Given that oaks are sessile and productive in maturity (McDonald 1969), the subsistence goals of California Indians encourage oak maintenance into late maturity (McCarthy 1993). Burning also reduces acorn pest infestations (Halpern 2016) and increases gathering efficiencies (McCarthy 1993). Furthermore, acorns are not immediate-return resources in contrast to most fauna; instead, acorns are well suited for long-term storage.

Such acorn storage properties likely contributed to the development of familial-controlled foods, sedentism, and usufruct resource rights associated with oak groves throughout the region (Huntsinger and Diekmann 2010; Tushingham and Bettinger 2013). Therefore, unlike burning for mobile species, burning for acorns is conducted intentionally and repeatedly in specific locations to maintain productivity, and thus, is compatible with contemporary conceptualizations of resource management such as swidden agriculture, and sustainable fishery management (Fowler and Lepofsky 2011; Lightfoot et al. 2013).

Indigenous burning of oak woodlands, along with other habitats (e.g., prairies) fostered deep ecological and spiritual ties/relationships between California Indians and these managed ecosystems. As Long et al. (2016) show, the wildlife benefits associated with oak woodlands were extensive, and support positive feedbacks and co-evolutionary relationships akin to such relationships documented between Martu and their prey (Bliege Bird et al. 2013; Codding et al. 2014). Hence, the proximate cause of burning was to enhance acorn quality and gathering, but had additional benefits for other subsistence activities (e.g., deer hunting). With the removal of burning across California, these relationships were destabilized and caused transitions to alternative stable states as well as contributed to trophic cascades with population declines and species extirpations throughout California (Estes et al. 2011). Of note are predators such as the Spotted Owl (*Strix occidentalis*) and the Pacific fisher (*Pekania pennanti* spp. *pacifica*) whose population declines have been strongly affected by the transition to a timber-based forest economy (Thomas et al. 2006; Zielinski 2013). Such species' populations formerly thrived through the heterogeneity and patch dynamics created and maintained by prescriptive cultural fires (Thomas et al. 2006; Long et al. 2016; Eyes et al. 2017). The re-introduction of cultural fire coupled with the fostering of Indigenous subsistence systems (Daigle 2017; Norgaard 2019; Sowerwine et al. 2019) provides a potential path toward re-constructing these human-oak relationships as well as populations of other fauna and flora that are dependent on the persistence of these fires.

The expansion of cultural and prescriptive burning on private and Tribally-owned properties in Karuk and Yurok territories is a result of protracted advocacy by Tribal members over decades (Chapter One; Senos et al. 2006; Baldy 2013; Diver 2016). When the resources associated with TREX became available in 2012, Tribal members, Tribes, and NGOs (e.g., Orleans Somes Bar Fire Safe Council, Cultural Fire Management Council) were prepared to conduct burns, and have become adept at leveraging these resources to increase burning capacity (Chapter Six; Butler and Goldstein 2010; Spencer et al. 2015; Terence 2016). While motivations for prescribed burning increasingly are focused upon fuel reduction—largely due to hazardous fuel accumulation—the cultural, spiritual, and subsistence motivations for cultural fires remain the major priorities for Karuk and Yurok Tribal communities (Baldy 2018; Norgaard 2019; Sowerwine et al. 2019).

Karuk Tribal members often describe themselves as 'Fix-the-world people' referencing their annual ceremony called "The World Renewal [which] is a communal ritual that…re-creates and renews the Earth and the Spirit Beings of the Earth" (Julian Lang in Field 2008: 92). Before the implementation of fire exclusion policies, a component of the ceremony included ritual burning of nearby mountains. Hence, burning is critical to repairing the world, and, as outlined by the Karuk Tribe, a major component of their philosophy is "working to repair and restore the complex social and ecological systems that make up the Klamath River Basin" (Karuk Tribe 2013). As the Karuk Tribe proposes, re-integrating cultural and subsistence uses into oak woodland restoration will increase important socio-ecological benefits (Kimmerer 2011; Bliege Bird and Nimmo 2018). A recent partnership between the Karuk Tribe and the USDA Forest Service includes black oak and hardwood restoration that integrates forestry techniques with cultural burning (USDA Forest Service PSW Region 2018). Efforts such as these have considerable potential to restore black oak dominated woodlands and to revitalize the Indigenous cultures and communities who historically altered oak densities and distributions through cultural burning and acorn subsistence.

CHAPTER 6

Facilitating Fire: Redressing Persistent Prescribed Fire Constraints in Northern California

ABSTRACT

Destructive wildfires in northern California are catalyzing government agencies and community organizations to embrace prescribed fire to redress hazardous forest fuel accumulation. Karuk and Yurok American Indian Tribes have advocated for expanding prescribed burning for decades and are leading innovative forms of fire governance. Through a case-study of prescribed burning in Karuk and Yurok Indian territories coupled with 75 surveys and 18 interviews with fire managers across northern California, this study identified material changes in personnel and policies that are facilitating the expansion of prescribed fires. Specifically, I identify a shortage of wildland fire teams required to conduct burns along with the need for additional specialists to plan and prepare environmental reviews for burn areas. Wildfires and extreme fire weather in other regions of California led authorities to impose statewide burn bans and to divert wildland fire personnel from conducting prescribed burns in areas where prescribed burning conditions are ideal. To address chronic underfunding on public lands and the high costs of burning on privately owned properties, communities and Tribes have developed decentralized prescribed burn associations, and independent, qualified prescribed fire teams. Interagency partnerships have also provided supplemental funding and personnel to support burning across multiple jurisdictions. Increased communication among regulatory bodies, particularly land management and air quality management agencies, has reduced bureaucratic constraints in permitting processes. Devolution of burning regulations together with support of Tribal fire and land sovereignty in areas that have established burning norms and infrastructure, has potential to accelerate prescribed fire implementation and expansion.

INTRODUCTION

Wildfires in California and the American West have caused unprecedented property destruction and human fatalities (Moritz et al. 2014; Kramer et al. 2019). As a result, federal and state land and fire management agencies have embraced prescribed and cultural burning to reduce wildfire intensity and rate of spread (Stephens et al. 2016). However, fire exclusion and suppression policies that initiated in the early 20th century remain persistent and constrain efforts to expand the pace and scale of prescribed burning in California (North et al. 2015; Schoennagel et al. 2017; Miller et al. 2020). In the absence of frequent anthropogenic and lightning-ignited fires, surface fuel loads and tree densities have increased, causing concomitant wildfire severity increases in the Sierra Nevada and southern Cascade mountains (Miller and Safford 2012; Mallek et al. 2013). In addition, the increased density of human settlements in forested areas has contributed to ecological fragmentation, and has produced a complex mosaic of diverse property owners, and, thus, prescribed fire planning has become increasingly complex with liability concerns (Hammer et al. 2007; Syphard et al. 2007; Yoder 2008; Joshi et al. 2019). Nevertheless, communities and fire managers in northern California are successfully expanding prescribed burning by capitalizing upon changes in federal and state policies, and establishing new prescribed fire advocacy and implementation organizations. In particular, the Karuk and Yurok American Indian Tribes have initiated successful efforts to revitalize cultural burning (Harling 2015; Vinyeta and Lynn 2015; Long and Lake 2018) by building polycentric, or inter-governmental and inter-institutional coalitions to manage fire across complex jurisdictional boundaries (Ostrom 2010; Kelly et al. 2019).

Here, I use a political ecology framework (Watts and Peet 2004; Robbins 2011) to examine how governance, land tenure, and resource distribution affect fire policy and the re-introduction of prescribed burning in northern California. Pyne (1982, 2004, 2016), Simon (2017), and Davis (1998) have scrutinized the effects of political economy on fire in California history. My focus here centers on the political ecology of prescribed fire in California Indian communities and across northern California and my analysis is informed by the effects of settler-colonialism (Wolfe 2006) and neoliberalism (Harvey 2007) on fire and forest management.

BACKGROUND

Before the effects of colonialism, California Indians intentionally set fires to reduce wildfire risks and to sustain critical subsistence and cultural resources, such as acorns and basketry materials (Anderson 2005; Lightfoot and Parrish 2009). The economy of California Indians depended upon the frequent and widespread use of fire to enhance local resources (Lightfoot and Parrish 2009), much like other pre-industrial, non-capitalist societies (Seijo and Gray 2012; Scherjon et al. 2015). The advent of settler-colonialism wrought death, violence and forced labor in California Indian communities (Norton 1979; Trafzer and Hyer 1999; Madley 2016), and was connected to a global capitalist system that emphasized commodity-based relations and wage labor (Marx 1967; Foster 2000; Moore 2015). Foresters trained in Germanic silviculture and timber production (Scott 1998) believed fire must be eliminated from the landscape in order to encourage timber regeneration and sustainable profits for the settler state (Show and Kotok 1924; Pyne 1982; Hudson 2011). This economic and political shift radically changed the distribution of fire and land ownership throughout California, as California Indian lands were converted to National Parks and Forests, as well as commercial timber estates and ranches (Ayres 1958; Spence 2000; Miller 2017).

The professionalization of fire management by the California Department of Forestry and Fire Protection and the US Forest Service emerged to address the crisis of destructive timber practices that created an extreme fire hazard with timber slash and residual woody fuels (Clar 1959; Laudenslayer and Darr 1990; Hudson 2011). In 1905, the US Forest Service was created to regulate the extraction of timber, but the only real regulatory authority the timber lobby initially allowed the Forest Service was the protection of commercial timber trees from fire (Hudson 2011). Federal and California state agencies successfully reduced fire frequency and extent with industrial-scale fire suppression that was dependent on a sizable workforce (Clar 1959; Pyne 1982). Ultimately, their management solution to the ecological crisis precipitated by timber extraction could not effectively eliminate wildfires, and instead produced a second crisis of fire suppression, or what Mark Hudson conceives as the “crisis of crisis management” (Hudson 2011: 123).

Expansion of the Wildland Urban Interface

As the United States situated itself as a core power in the world capitalist system (Wallerstein 2000), extractive multi-national industries emerged in California (Brechin 2006) followed by rapid suburban housing construction to accommodate California's expanding resident population (Walker 2001; Pincetl 2003). However, since the 1960s, timber extraction declined as a direct result of over-extraction coupled with global market competition (Prudham 1998; Morgan et al. 2004). In the Sierra Nevada and coastal mountains, real estate and housing industries purchased post-industrial timber lands and developed them into residential settlements for retirees, vacationers, and those who were able to work remotely, or willing to commute (Duane 1999; Walker and Fortmann 2003; Bliss et al. 2010). These areas are called both the 'Wildland Urban Interface' (WUI) or 'exurban' (Duane 1999; Egan and Luloff 2000; Brenkert-Smith et al. 2006; Löffler and Steinicke 2006; Larsen et al. 2011; Beebe and Wheeler 2012; Roberts 2013; Abrams 2016). The WUI is socio-economically diverse; these areas have retained households who were either formerly or continue to be reliant on the extractive economy or have entered the service economy, and also attracted retirees on fixed incomes (Walker and Fortmann 2003; Collins 2005; Hiner 2014). Wealthier WUI residents are often referred to as 'amenity migrants,' given their affinity toward the privacy and recreational opportunities associated with residing near public lands (Gosnell and Abrams 2011). Amenity migrants do not rely on the land for their livelihood and are often considered 'absentee' property owners. They also are less likely to have experience with fire management, and thus, they tend to be apprehensive toward implementing prescribed fire treatments to reduce hazardous forest fuels (Vogt 2002; Carroll et al. 2004; Fischer and Charnley 2012; Roberts 2013).

The parcelization and development of areas near surrounding fire-prone national forests and public lands has caused the fire suppression infrastructure to shift its focus from protecting commercial timber to protecting residential communities (Calkin et al. 2014; Fischer et al. 2016; Schoennagel et al. 2017). In 2015, over 50% of the USDA Forest Service budget was spent on suppressing fires within the WUI, primarily to protect private properties (USDA Forest Service 2015; Schoennagel et al. 2017). In contrast, spending for local fire protection services in California WUI areas declined with the 1978 passage of Proposition 13, which reduced parcel taxation and, in turn, local government revenues (Simon and Dooling 2013; Simon 2014). Increasing parcel fragmentation and limited property tax revenues have created an increasingly difficult land-ownership mosaic to coordinate and to implement hazardous fuel mitigation (Paveglio et al. 2009; Fischer and Charnley 2012; Fischer et al. 2016).

From an American Indian perspective, the subversion of Tribal land sovereignty through Forest Service dispossession and federal and state fire exclusion policies placed the responsibility of increased wildfire risk overwhelmingly on capitalist and state actors (Huntsinger and McCaffrey 1995; Mason et al. 2012; Lake et al. 2017; Norgaard 2019). The expansion of the WUI by the real estate industry and the state persistently erases and renders the history of California Indian land tenure and use invisible (Middleton 2015). Through their ability to raise capital from their gaming industries' revenues and their organized efforts to regain land through land trusts, conservation easements, and purchases (Middleton 2011), Tribes have increasingly acquired power and political influence in California. Since Clinton's 1994 executive order, the implementation of Federal-American Indian consultation within federal planning processes also created opportunities for recognized Tribes to influence fire and land management (Dockry et al. 2017; Long et al. 2018b). However, Tribal members as well as low-income communities in rural areas and the WUI remain disproportionately exposed to wildfire hazards in the American West (Collins 2008; Davies et al. 2018).

Wildfire Policy and Prescribed Burning

To address the increasing threat of wildfire to the WUI, US Congress passed the Healthy Forests Restoration Act (HFRA) in 2003 to increase hazardous fuel reduction activities including prescribed burning (Davis 2004; Steelman and Burke 2007). This legislation categorically excluded some fuel reduction projects from environmental assessments and environmental impact statements under the National Environmental Policy Act (NEPA) and limited opportunities to appeal projects (Davis 2004). Yet, the HFRA also promoted community-based, collaborative decision making to plan and to conduct these fuel treatments through Community Wildfire Protection Plans (Jakes et al. 2011). The HFRA also transferred considerable funds for fuel reduction and prescribed burning toward private stewardship contracts as opposed to increasing government personnel for these projects (Steelman and Burke 2007; Moseley and Charnley 2014). Notably, the focus of prescribed fire use in the HFRA is oriented toward the protection of homes in the WUI, and thus, may serve to discount ecological and cultural objectives for prescribed burns of central importance to Tribes and environmental NGOs (Steelman and Burke 2007; Long et al. 2018b).

In Karuk Tribal territory, an HFRA project initiated by the Six Rivers National Forest called the Orleans Community Fuels Reduction Project went through public scoping and multiple environmental reviews beginning in 2006 (USDA Forest Service 2008). The Forest Service attempted to collaborate and consult with NGOs and the Karuk Tribe to develop a plan to reduce hazardous fuels by thinning trees and conducting prescribed burns (USDA Forest Service 2008). While the Tribe and community organizations advocated for actions based on proposals in the Orleans-Somes Bar community wildfire protection plan, the Forest Service initiated a plan that was eventually halted because a private timber contractor destroyed Karuk ceremonial trails and removed excess timber to offset the costs of fuel reduction treatments (Scott-Goforth 2013; Tripp 2019).

McCarthy (2005) argues that policy changes such as the HFRA are indicative of neoliberal policies in American governance that downsize government spending, privatize services formerly conducted by the state, and eliminate regulatory protections. Neoliberalism is a form of market fundamentalism favored by capitalists to re-enter and liberalize markets that, in the United States, had been highly regulated until the 1980 election of President Reagan (Harvey 2007). Hence, the deregulation and privatization of hazardous fuel reduction in the HFRA was viewed by environmentalists as a strategic move by the timber industry—under the guise of wildfire risk reduction—to re-enter public lands after years of environmental protections (e.g., NEPA of 1970, the National Forests Management Act of 1976, and the North West Forest Plan of 1994) had reduced the availability, commercial stocks, and profitability of timber extraction (Hibbard and Madsen 2003; Davis 2004). Environmental NGOs (e.g., the Wilderness Society, Sierra Club, and others) thought the timber industry would use hazardous fuel reduction and the HFRA to thin forests and extract profitable timber trees that had ecological importance (Hibbard and Madsen 2003; Davis 2004).

The implementation of the HFRA has lacked sufficient government oversight and documentation (Steelman and Burke 2007). However, the community wildfire protection planning component of this law has, in some cases, expanded prescribed burning and decentralized resource governance (Fleeger 2008; Williams et al. 2012; Jakes and Sturtevant 2013). Additionally, the stewardship contracting component of the HFRA has also supported NGOs and private contractors to complete restorative projects (Fleeger 2008; Jakes et al. 2011). However, whether hazardous fuel reduction is outsourced or conducted by state employees, the efficacy of these projects has been questioned because of their relatively poor labor standards, and inattentiveness to ecological principles (Roberts 2013). Empirical studies have demonstrated that if mechanical treatments are initially used, they should be followed by repeated prescribed burning to maintain reduced fuel loads (Collins et al. 2010). However, the implementation of prescribed burning in California has been far less prevalent than mechanical treatments (Vaillant and Reinhardt 2017; Kolden 2019).

In addition to the HFRA, the federal government has developed other initiatives that emphasize collaborative efforts to restore prescribed burning and promote wildfire resilience. The Tribal Forest Protection Act of 2004 allowed Tribes to propose collaborative fuel reduction projects with the Forest Service on Forest Service lands (Lucero and Tamez 2017). However, few projects have been implemented due to limited Tribal capacity and, in contrast to the HFRA, the TFPA legislation did not appropriate funds for developed projects (Lucero and Tamez 2017). The USDA has also sponsored multi-jurisdictional collaborative fire restoration projects through funds such as the Collaborative Forest Landscape Restoration Program (CFLRP) in 2010 and the Joint Chiefs Landscape Restoration Program (JCLRP) in 2014 that have been most successful where community organization has been strong (Butler 2013; Kelly et al. 2019; Cyphers and Schultz 2019). The Fire Learning Network (FLN) was initiated in 2002, and this program is led by the Nature Conservancy and supported by the Forest Service and Department of Interior. The FLN funds collaborative fire planning and prescribed fire TRaining EXchanges (TREX) to increase community capacity for prescribed fire expansion (Butler and Goldstein 2010; Spencer et al. 2015). FLN engagement has prepared participating communities to receive additional support from the CLRFP and JCLRP (Butler and Goldstein 2010), and develop decentralized burning networks such as the Indigenous Peoples Burning Network and the Humboldt Prescribed Burn Association in northwest California (Robbins et al. 2016; Crowder 2019).

In California, several additional state initiatives aim to support community-based fire planning and restoration (Ganz et al. 2007; Everett and Fuller 2011; Manning and Reed 2019). The California Department of Forestry and Fire Protection (CAL FIRE) developed the California Fire Safe Council in 1993 that eventually became an independent non-governmental organization (NGO) supporting community-based Fire Safe Councils (FSCs) throughout the state (Everett and Fuller 2011). FSCs typically educate community members on defensible space, and also may conduct larger-scale fire planning and hazardous fuel reduction (Ganz et al. 2007; Everett and Fuller 2011). In 2018, CAL FIRE also initiated the Forest Health Grant Program using funds from the state cap and trade carbon market under the California Air Resources Board (AB32; Blanchard & Vira 2017; Manning & Reed 2019). This CAL FIRE grant program has been used to fund prescribed fire projects across multiple jurisdictions. In addition, CAL FIRE staff conduct CAL FIRE's Vegetation Management Program, and directly supports fuel reduction projects on private lands by partnering with landowners. However, treated areas declined by 65% (3356 ha year^{-1}) in the late 1990s and 2000s because of an increasing priority on fire protection and suppression (Scanlon and Quinn-Davidson 2019).

In 2009, Quinn-Davidson & Varner (2012) conducted a survey of 70 northern California fire managers to evaluate their perceived impediments to implement and expand prescribed burning. They found that managers rated a narrow burn window—or political and ecoclimatic conditions that limit prescribed burning, environmental and air quality regulations, and paucity of trained personnel to conduct burns, as the major constraints to expand prescribed fire in northern California. Since Quinn-Davidson & Varner's 2009 survey was conducted, the Fire Learning Network established a strong presence in northern California, and the aforementioned federal and state programs were implemented (e.g., CFLRP, JCLRP, CAL FIRE Forest Health Grants). Moreover, considerable progress with both grass-roots and California Indian organizing has helped establish many partnerships with state and federal agencies to support prescribed fire expansion (Harling 2015; Vinyeta and Lynn 2015; Crowder 2019).

In this study, I asked managers what they believed could materially or politically reduce constraints for expanding prescribed burns that were identified in Quinn-Davidson & Varner's study (2012), and also to evaluate whether partnerships and certain actions were facilitating prescribed fire expansion. Here, I examine a dataset of interviews and surveys with northern California fire managers as well as case-study observations from prescribed fires in the Klamath mountains of northwest California with the aim to assess factors that potentially facilitate or constrain the expansion of prescribed fire throughout northern California. Through interviews, surveys, and participant observations, I asked managers to share what actions were undertaken to implement prescribed burns as well as what specific changes in personnel (labor) and regulatory frameworks would allow them to expand these burns. While several studies inform this study (Biswell 1999; Quinn-Davidson and Varner 2012; Schultz et al. 2018; Miller et al. 2020), here I distinctively use a political ecology framework and Indigenous perspectives to re-evaluate the status of prescribed burning in California.

METHODS

Study Region

For the purposes of this study, northern California was defined as all counties north of Marin, Sonoma, Napa, Solano, Sacramento and El Dorado counties to the Oregon border (136,318 km^2). The region has a Mediterranean climate, with wet winters and dry summers with a north-south and west-east gradient of decreasing precipitation, as well as an elevational gradient of increased precipitation (van Wagtendonk et al. 2018). The numerous mountain ranges, including the coastal range, Klamath mountains, Cascade mountains and the Sierra Nevada mountains produce exceptional ecological and climatological diversity. Prescribed burning usually occurs during seasons of transition (dry-wet) when fuel moistures are between ~8% and 15%, typically in spring and fall (Biswell 1999). Counties in the Sacramento and the San Francisco Bay Areas are the most densely populated areas in this region, with other cities in Shasta (Redding), Butte (Chico), and Humboldt (Eureka) counties. National Forests and Parks encompass 35% of the regional area (47,176 km^2).

Interviews, Surveys, and Prescribed Fire Observations

From 2014 – 2019, I observed prescribed fire planning and implementation in Karuk and Yurok Indian territories within the Klamath River watershed of northern California. My observations of prescribed fire planning occurred at 13 Cultural Fire Management Council meetings that are open to community members in and around Weitchpec, California, a village on the Yurok reservation. At these meetings, I transcribed interactions and developed relationships with leaders of the organization. Planning also occurred during prescribed fire training exchanges, where I observed the logistical decision process to implement burns. Participatory observations were conducted during prescribed burning at the Yurok (2015 – 2019; n = 8) and Klamath (2016 – 2019; n = 4) prescribed fire training exchanges. During these events, I also inquired and discussed decisions made with fire managers and participants who conducted burns. I also spoke with managers about specific prescribed burns conducted by the USDA Forest Service on the Klamath and Six Rivers National Forests.

I conducted semi-structured interviews with 18 fire managers from prescribed fire training exchanges in the Klamath watershed, and with fire managers who responded to an online survey. These online surveys were developed using Qualtrics surveying software (Qualtrics International, Inc., Provo, Utah) and then distributed in February - March, 2019 to 190 fire managers employed by the USDA Forest Service, National Park Service, Bureau of Land Management, US Fish and Wildlife Service, US Natural Resource and Conservation Service, the California Department of Forestry and Fire Protection (CAL FIRE), California Fire Safe Councils, and Tribes in 26 Northern California counties. Managers are defined here as individuals who plan and supervise prescribed burning as opposed to those who only conduct burns. Therefore, managers included those at multiple levels of organizational hierarchies. Participant contact information was collected from National Forest Schedule of Proposed Action reports and prescribed fire announcements, as well as from agency or organizational databases, and directly from regional fire managers employed by various agencies. This online survey was developed from previous in-depth interviews with fire managers, and included questions on what facilitated the expansion in area and frequency of prescribed burns as well as their perceived constraints (Appendix A). To analyze these data, I generated descriptive statistics, and used a grounded theory approach to inductively code survey and interview responses (Glaser and Strauss 2017).

RESULTS

Klamath Watershed Case Study

Leadership by Karuk and Yurok Tribal members has been instrumental to expanding cultural and prescribed burning in California's Klamath watershed. Compared with prescribed burns, cultural burns reflect Indigenous objectives to enhance culturally-important species, such as acorns and basketry materials, and habitats (which include meadows and oak woodlands for deer and elk). Tribal leaders strongly articulate the relationships among commercial timber extraction practices, fire suppression policies, and the production of the wildfire crisis. Both in interviews and in public settings, these leaders consistently posit that cultural burning and Tribal sovereignty over ancestral territory are solutions to this crisis. The promotion of cultural burning has helped establish regional partnerships and plans with cultural burning as a key restoration priority.

Tribal fire managers express that they have overwhelming support for expanding cultural burning in the region, which is reflective of the vital role it plays in northern Californian Indigenous culture. Margo Robbins, the President of the Cultural Fire Management Council (CFMC) that leads cultural burning on the Yurok reservation, tells the story of how a 2012 grassroots survey of residents in the southeastern portion of the Yurok reservation identified expanding cultural burning as the highest priority for the community, which led to the creation of the CFMC. Fire managers in the region also identify that there is more demand for cultural burns on privately owned properties that they can provide, and that they do not sense opposition to cultural burning from residents. Given that many property owners in this region cannot obtain fire insurance, they feel that they must reduce risks on their own, and prescribed burning is an effective means to do so. The success of initial prescribed burns has garnered managers enhanced 'social license' and public support to expand the practice.

Expanding Prescribed Fire Capacity

The Karuk Tribe's Department of Natural Resources (Karuk DNR) has invested and raised considerable financial resources and has initiated numerous partnerships with non-governmental and governmental agencies to plan and implement cultural burns on land under federal jurisdiction, as well as private and Tribally-owned properties. Specifically, Karuk DNR has partnered with the Orleans Somes Bar Fire Safe Council (OSBFSC) to coordinate the Western Klamath Restoration Partnership, which is working to expand cultural burning within ancestral Karuk territory under the jurisdiction of the USDA Forest Service. In 2018, the Partnership completed the NEPA review process on a pilot project to burn ~2250 ha. The CFMC partners with the Yurok Tribal government, non-governmental organizations, and the California Department of Forestry and Fire Protection (CAL FIRE) to conduct cultural fires on the Yurok reservation. The Fire Learning Network and Prescribed Fire Training Exchanges (TREX), each coordinated by the Nature Conservancy, have provided critical initial funding and resources for the CFMC and Karuk DNR to initiate partnerships and conduct burns.

TREX initially brought personnel to the region with the necessary qualifications to conduct cultural burns because the Karuk DNR, CFMC and the OSBFSC did not have expertise recognized by the federal or state governments to conduct burns independently. CAL FIRE has not granted permits for cultural burns without burn plans (developed by specialists, such as burn bosses and registered foresters) that typically require > 20 qualified personnel during the burns, depending on the burn area. Recently, TREX has helped train local staff and residents to increase their qualifications to support future prescribed burning expansion.

Karuk DNR and CFMC have leveraged TREX and Fire Learning Network resources to raise additional funds from CAL FIRE, the Humboldt County Area Foundation, the National Wildfire Coordinating Group, the Bureau of Indian Affairs, and many others. These funds have allowed Karuk DNR to bolster the staff and qualifications of their wildland fire department, and in partnership with the OSBFSC, establish a year-round prescribed fire team and acquire necessary equipment (e.g., engines) to conduct prescribed burns. The CFMC also facilitated the hiring of additional personnel within the Yurok wildland fire department to augment their qualifications and ability to plan and conduct cultural burns independently.

The increase in staffing has strengthened capacity and expanded prescribed and cultural burning in the region, however, managers believe it is still insufficient, and additional funds are necessary. The regional cost of preparing privately-owned fire-excluded sites for prescribed burning is between $1500 - $2500/acre ($600 - $1000/ha; N. Bailey, pers. com., 2018) and prescribed burning is ~$3800/acre ($1520/ha; E. Darragh, pers. com., 2019) based upon wages in

FY 2018. Observed burns, on average, used 23 personnel, and spent 41 – 65 personnel hours per hectare burned (Table 1). Costs would decrease as burn area expands and sites are repeatedly treated, but it is a relatively heterogenous geographical region and state and federal investment has not been provided at scale.

Regulatory and Budget Constraints

Obtaining air quality permits in this region has not been difficult because it is both relatively remote from high density population centers, and Tribes, NGOs and the Forest Service have good relationships with the North Coast Air Quality Management District. However, local, state and region-wide burn bans have prevented prescribed burning from occurring in the Klamath basin during optimal prescribed fire conditions from 2016 – 2019. The Humboldt-Del Norte CAL FIRE Unit revoked a permit for the Yurok TREX in 2016 because they considered conditions to be too risky. In 2017 and 2018, large wildfires in other areas prompted the USDA Forest Service and CAL FIRE to shut down burning throughout the state. In 2019, an escaped prescribed fire in the El Dorado National Forest in the Sierra Nevada prompted the USDA Forest Service to ban ignitions in other National Forests, which effectively prevented the Klamath River TREX, organized by Karuk DNR and OSBFSC, from burning for a week. These centralized decisions are especially demoralizing for TREX because they convene volunteer fire professionals from around the world who are working to increase their skills and qualifications for a 1 – 2 week period established months in advance. Thus, to have excellent burning conditions met with the revocation of permits has been quite frustrating for participants and leaders who have invested considerable time and funds to conduct prescribed burns. Officials within state and federal management agencies relay to local fire managers that allowing prescribed burns while wildfires burn elsewhere could create misperceptions that the government is not doing enough to protect homes and built infrastructure.

The USDA Forest Service has flexibility to burn throughout the year, however, upper management often limits burning because of insufficient personnel or funds to conduct prescribed burns. The Forest Service typically requires that contingency fire engines and personnel are made available during burns to reduce risk. As a matter of practice, these engines are less likely to be available if there is a wildfire burning elsewhere, or if there was an arduous wildfire season preceding the fall prescribed burning season. Additionally, the fall prescribed burning season typically occurs at the onset of the fiscal year (October 1), and upper management are reportedly hesitant to allocate funds for prescribed burning if they anticipate a budget shortfall. Because of the long hours required to prepare and monitor a burn to ensure it does not escape, prescribed burning also typically requires that staff receive overtime pay. Overtime pay must be pre-approved for prescribed burns, which is another bureaucratic obstacle for prescribed burning in the region.

Some Forest Service managers speculate that National Forests that garner relatively high timber sale revenues also have more unrestricted monies to use for prescribed burning. Thus, National Forests with community opposition to extraction, or relatively larger ‘Late Successional Reserves’ established under the Northwest Forest Plan for Spotted Owl protection, can be at a budgetary disadvantage to conduct prescribed burns. Furthermore, Forest Service and Tribal managers are frustrated with what has become a management focus on a single species, as opposed to the importance of prescribed and cultural fire to enhance overall ecosystem functionality for multiple species and Indigenous cultures negatively-effected by timber-based management.

Tribal and Forest Service managers report that some environmental organizations and wildlife biologists employed by the Forest Service are opposed to human intervention in forest management, including cultural burning, which encumbers the National Environmental Policy Act (NEPA) planning process. Some forest managers also become more risk-averse toward integrating burning into forest management because of this highly scrutinized process. This contentious political context and the understaffing of environmental specialists can cause the process to require two or more years to receive approval for burning on National Forest lands. However, as one Forest Service manager stated: “You can have all the NEPA in the world, but if you can't obtain funding and/or there are no resources like hand crews and engines to burn because they are off fighting fire, or are too tired from a long season, then the program is not effective”.

Indigenous Fire Governance

Outside of Tribal and government agencies, the Indigenous Peoples Burning Network (IPBN) is a new inter-tribal grassroots formation receiving support from the Fire Learning Network. One of their main goals is to support family-based burning for fuel reduction and fire-enhanced eco-cultural species. Families cooperatively support each other to burn on their land, and have access to equipment from the CFMC. Leaders in the IPBN say that this form of decentralized burning reflects traditional governance of land and fire, and is a way to assert Tribal and familial sovereignty. However, this model has been more effective at conducting burns in Yurok territory where Tribal members still retain property or allotments on the reservation. In Karuk territory, there are fewer lands that remain under Indigenous ownership, and most resource tracts remain under the authority of the Forest Service. Hence, the IPBN model is less effective in areas with relatively greater Tribal land dispossession

Table 8. Average Personnel Hours and Fuel Used by Prescribed Burn Managers by Affiliation in the Klamath Watershed. Personnel hours were calculated by multiplying the time spent at a burn site by the total personnel conducting the burn. Personnel included all staff including burn bosses and wildland fire crews. USDA Forest Service (USFS) burns were conducted on the Klamath and Six Rivers National Forests in 2017. Prescribed Fire Training Exchange (TREX) burns were observed from 2017 – 2019. Standard errors (±) shown in parenthesis.

Affiliation	Burn area (ha)	Personnel (individuals)	Personnel (hr)	Personnel hr ha^{-1}	Fuel ($l\ ha^{-1}$)
USFS (*n* = 7)	12.6 (8.0)	23.1 (4.6)	222.8 (71.1)	40.5 (4.5)	17.0 (2.3)
TREX (*n* = 19)	7.0 (2.2)	23.7 (1.3)	213.2 (39.8)	64.8 (13.1)	17.8 (2.6)

Prescribed Fire Expansion Across Northern California

Interagency Partnerships

Of 190 email and phone requests, 75 managers were surveyed and/or interviewed, producing a 40% response rate. These managers spanned nine national forests, the Pacific Southwest Forest Service regional office, Redwood National Park, Whiskeytown National Recreation Area, five CAL FIRE units, eight fire safe councils, four Tribes, the USDA Natural Resource Conservation Service and California State Parks (Fig. 1). Throughout northern California, fire managers are frustrated with the slow expansion of prescribed fire. Concerted efforts by managers have produced only marginal improvements in achieving local prescribed burn targets and objectives. Since 2013, 71% of managers stated that they have made progress toward increasing the annual area receiving prescribed burning treatments. The formation of interagency partnerships was viewed by managers as the most effective action to increase prescribed burning area (Fig. 2), as over 50% of managers reported that these interagency partnerships assisted them to surmount funding, personnel, and equipment limitations (Table 2). Partnerships between government agencies and NGOs particularly assisted managers in gaining support from local residents. Other important management actions included: 1) increasing agency capacity by hiring additional staff; 2) enhancing the qualifications of existing staff; and, 3) proactively planning and implementing burns (Fig. 2).

Interagency partnerships also helped surmount bureaucratic bottlenecks and navigate differences regarding smoke permitting. Public land agencies began to meet with the California Air Resources Board (CARB) as the Interagency Air and Smoke Council (IASC) in the late 1990s to reduce citations and fines and establish improved communication to clarify land manager objectives and streamline processes. A product of this regional leadership was the creation of the Prescribed Fire Information Reporting System, which provides a mechanism for communicating directly between air regulators and fire managers. All federal fire managers surveyed stated that air quality permitting had either improved or had not changed since 2013, reflecting these efforts to improve communication at the regional level. Individual managers shared that bringing local air quality managers to prescribed fires and sending them photos of smoke columns helped open positive lines of communication. However, amongst NGOs and CAL FIRE managers, 41% stated that air quality permitting had declined in the same period. CAL FIRE and NGOs have been minimally involved in the IASC until recently, and in some regions (e.g., near urban areas), local Air Quality Management Districts remain apprehensive toward additional emissions from prescribed fires, and impose cost prohibitive fees on prescribed fires.

Thirty percent of managers identified that changing air quality regulations in the Clean Air Act to exempt smoke from prescribed burns as a priority and would effectively prevent regulatory discrepancies between different air quality management districts. Recent large wildfire events, however, have shifted the conversation, and air quality managers are seeing the benefit of prescribed burning to reduce wildfire smoke emissions.

Managers also recognize that some rural and WUI residents are inexperienced with prescribed burning resulting from the legacy and persistence of the Forest Service's Smokey Bear campaign messaging and the transition to recreational and vacation land uses. This presents another challenge toward the widespread adoption of prescribed fire. However, Fire Safe Councils (FSCs) are a venue for communities to prepare for wildfire through prescribed burning, and have done considerable public outreach on the importance of prescribed burning and defensible space. Across all managers, 41% believed public concerns toward prescribed burning had improved, whereas only 18% thought they had declined. However, one FSC leader noted that: "The people who aren't here year round don't like to participate [in the FSC]. Most think that the more trees there are the better, so to explain to them that they need to thin and burn the trees is tough". Furthermore, most FSCs are volunteer-run and do not have paid staff. Hence, the complex permitting requirements, liability issues, and associated costs of prescribed burning present challenges for Fire Safe Councils to organize burns.

Those FSCs that have the infrastructure for staff, like the Plumas County Fire Safe Council, have recently initiated prescribed burns and created positive partnerships with public land agencies. FSCs that do not lead burns themselves are excellent vehicles for communicating the benefits of agency-led prescribed burning, and have helped plan prescribed fire treatments on national forest lands. Over 50% of all public land managers interviewed stated that community collaborations supported with public outreach, and only 26% of all managers felt that private properties discouraged the planning of prescribed burns 'most of the time'. Additionally, although not directly asked about public outreach, two public land fire managers shared that a greater investment in hiring public information officers would improve communication with residents in the wildland-urban interface to promote greater acceptance of prescribed burning.

Wildfire Suppression

While wildfires have increased awareness of the importance of prescribed burning, they have also prevented managers from burning by reducing available personnel. Managers identified 'wildfires reducing available personnel' as the top constraint limiting their opportunity to burn, or 'burn window' (Fig. 3). In northern California, burn conditions are often ideal when southern

California is experiencing wildfires, and personnel are requested to support in suppression efforts. However, as one manager noted: “Quite often we have to be on stand-by because there is a fire that doesn’t even exist. This is preventing us from burning”. Hence, in the fall burning season, northern California prescribed fire teams are unable to burn because agency leaders would like them to be available for relocation if a wildfire occurs. However, many managers also concede that the fire season has expanded with climatic changes, which also limits their access to wildland fire crews to conduct burns.

Managers recognized that an institutional culture of risk aversion is another major constraint to their burn window (Fig. 3) that comes from upper managers who fear potential political liabilities that may occur either from escaped fires or burning during large wildfires. “[The] current forest supervisor comes from the old timber mind set and has been known to be risk averse to burning”. Hence, lower-level managers are pulled in different directions by rhetoric coming from the regional or national level that supports prescribed burning, and the apprehension of national forest supervisors or CAL FIRE unit chiefs who must deal with complex political realities. CAL FIRE, for example, has only recently re-embraced prescribed burning as an important strategy under the leadership of director Ken Pimlott (2010 - 2018). As one CAL FIRE manager stated, “In the 2000s, when we got away from large scale broadcast burns, we brought on a lot of firefighters, and many of those folks are now battalion chiefs and leadership. So, they may not have participated in [prescribed fire] projects”. The fire suppression culture that was fostered for decades has made many leaders uncomfortable and unfamiliar with prescribed fire.

Personnel and Funding Requirements

The greatest staffing needs for fire managers are trained wildland fire crews who can conduct and prepare areas for prescribed burns. Managers consistently ranked these crews as the most beneficial means to expand prescribed burning capacity, and managers ranked hiring personnel to implement burns highest amongst all categories to increase financial resources (Fig. 4). As one manager stated, “There is going to be a workforce shortage to accomplish the acres needed to be treated. California will need a guest worker program or a civilian work program. State Parks will need more funding to treat more acres. Our burn budget has been stagnant for decades”. In the past three years, CAL FIRE has hired ten additional crews to reduce fuels and conduct prescribed burns. Managers felt that this was a promising development, however, in the National Forests, these crews are woefully insufficient despite the recognized need.

Managers also expressed that understaffing of environmental planners and cultural resource or other specialists who help conduct NEPA and California Environmental Quality Act (CEQA) reviews and studies for proposed prescribed burning slows their ability to burn. For CAL FIRE projects, CEQA review is required, and few specialists are available to support with the necessary evaluations. Across all jurisdictions, the major constraint remains sufficient cultural resource specialists to conduct archaeological reviews, followed by environmental planners to coordinate and evaluate project effects on wildlife and other species. One manager stated that: "Recruitment of specialists to rural areas is difficult. Retention is also difficult due to heavy workloads and lack of support". Another manager noted that there can be political disagreements between fire managers and specialists, which can stall or prevent projects from moving forward: "they hold up projects and put on so many design criteria to make it super challenging to get our work done".

When asked about supportive changes to law and policy to expand prescribed fire, the most frequently suggested change identified by 32% of managers was to reform NEPA and CEQA. One manager believed a recent change to NEPA enacted in the 2018 Consolidated Appropriations Act of the US Congress would be beneficial as it allows wildfire resiliency projects to be categorically excluded from environmental review. Other managers believed that California legislation in 2018 that exempted certain fuel reduction projects from additional CEQA review (e.g., those already reviewed under NEPA), held promise for streamlining prescribed burning. However, some CAL FIRE managers are skeptical that these changes will be effective without increased staffing because other CAL FIRE policies remain that require internal reviews, which require similar labor.

Many managers sense that fire policies are changing primarily as a consequence of the devastating wildfires in northern California in 2017 and 2018, but they report that they are stymied from substantial progress without increased funding. Within the federal agencies, some believe that the changes in wildfire suppression funding from the 2018 consolidated appropriations act will provide additional funds for prescribed burning. Yet, 72% observed that their budgets have been either stagnant or in decline. Hence, managers have sought to supplement resources to advance their projects. If their unit or forest has limited internal funds, they have applied for funding from national or regional sources or have collaborated with NGOs to apply for new CAL FIRE grants funded through the carbon offset market. In some jurisdictions, new county taxes are creating financial sources of support for managers as well.

Decentralizing Prescribed Burning

Managers who work on prescribed burning on private lands see the emergence of prescribed burn associations as an important cooperative effort given the additional regulatory burdens if projects receive state funding and liability coverage. The University of California Cooperative Extension and Northern California Prescribed Fire Council have supported the formation of a successful prescribed burn association among ranchers in central and southern Humboldt County that has prompted interest in the model from other managers throughout the region. To support such independent burning initiatives and to encourage the expansion of prescribed burning, managers believe that liability laws for authorized burners (e.g., property owners and burn bosses) should shift from simple to gross negligence, and that the state should facilitate the procurement of insurance for such prescribed fire associations. Furthermore, managers feel that those who participate in prescribed burning should not be required to receive qualifications through the state or federal certification systems, which are oriented toward training paid professionals to conduct wildfire suppression. They propose that the state adopt an alternative standard and system to increase the accessibility and inclusivity of prescribed burning for volunteers and community members. In this way, burning may become less a practice solely of government-sanctioned ‘experts’ and integrated into the management repertoire of private landowners throughout northern California.

Much of the advocacy for prescribed fire regulatory changes originates from the Northern California Prescribed Fire Council, which was established in 2009 by NGOs and professional fire managers to create a forum for managers and property owners to exchange information, practices, and advocate for prescribed burning. This network has provided recommended language for legislative changes to facilitate prescribed fire expansion and has shared best practices and advice for fire managers throughout the region.

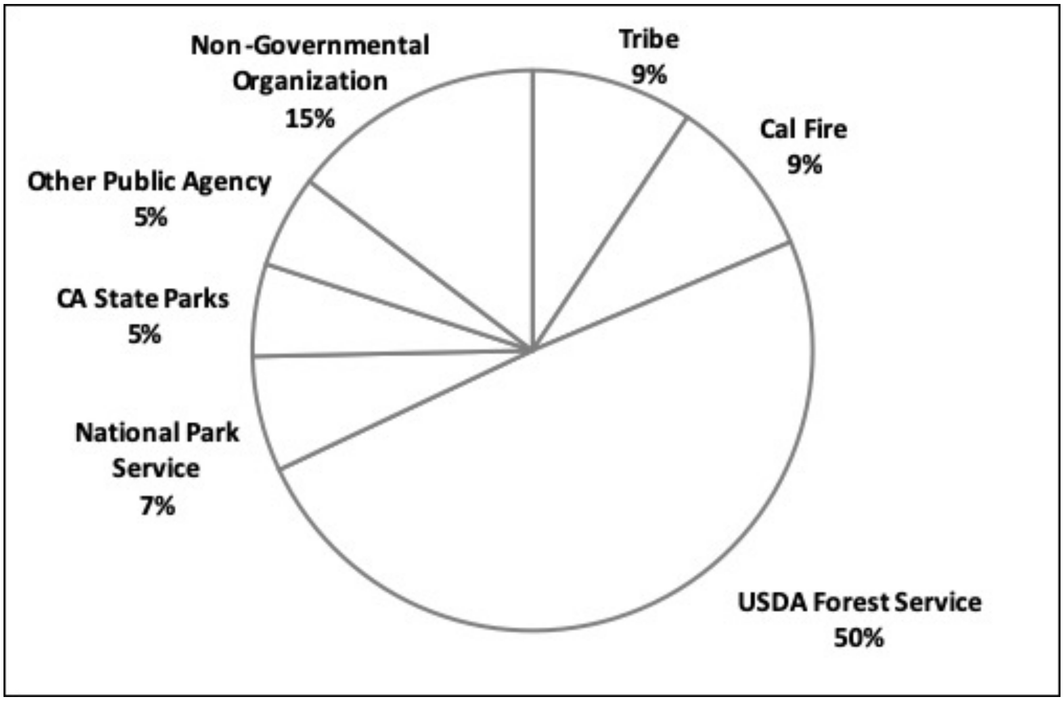

Figure 28. Affiliation of Fire Managers Who Participated in Surveys and Interviews. A total of 75 fire managers participated from 2016 – 2019.

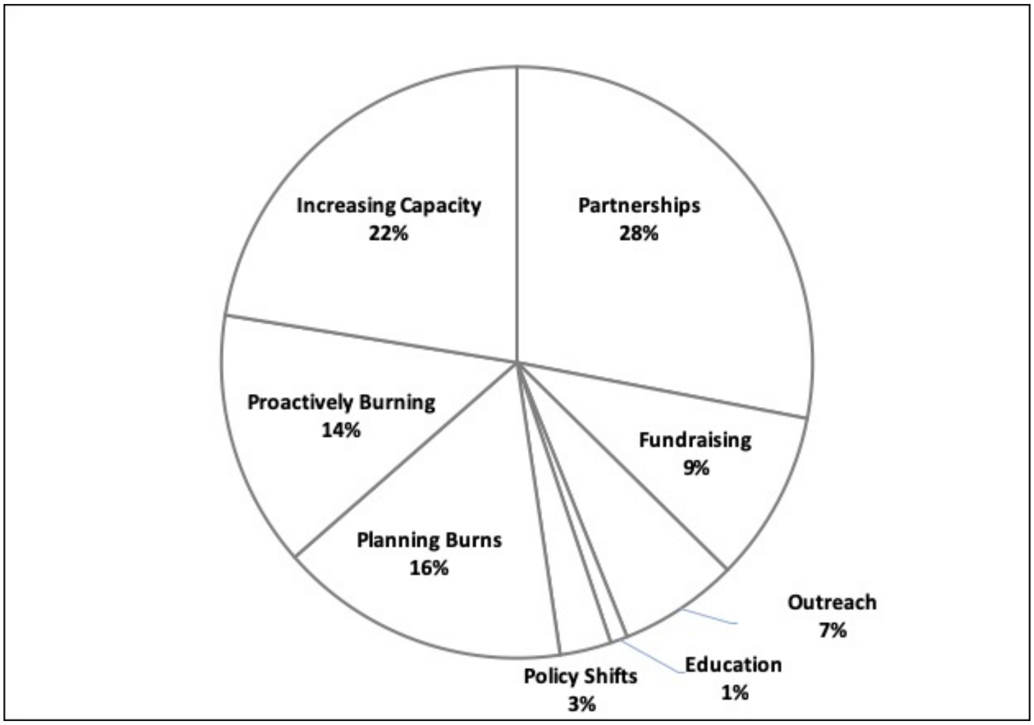

Figure 29. Effective Actions That Increased Prescribed Burning in Northern California. Fire managers were asked to identify their top three actions they took to increase prescribed burning in their agency, organization, or Tribe. Their responses were coded and then summed.

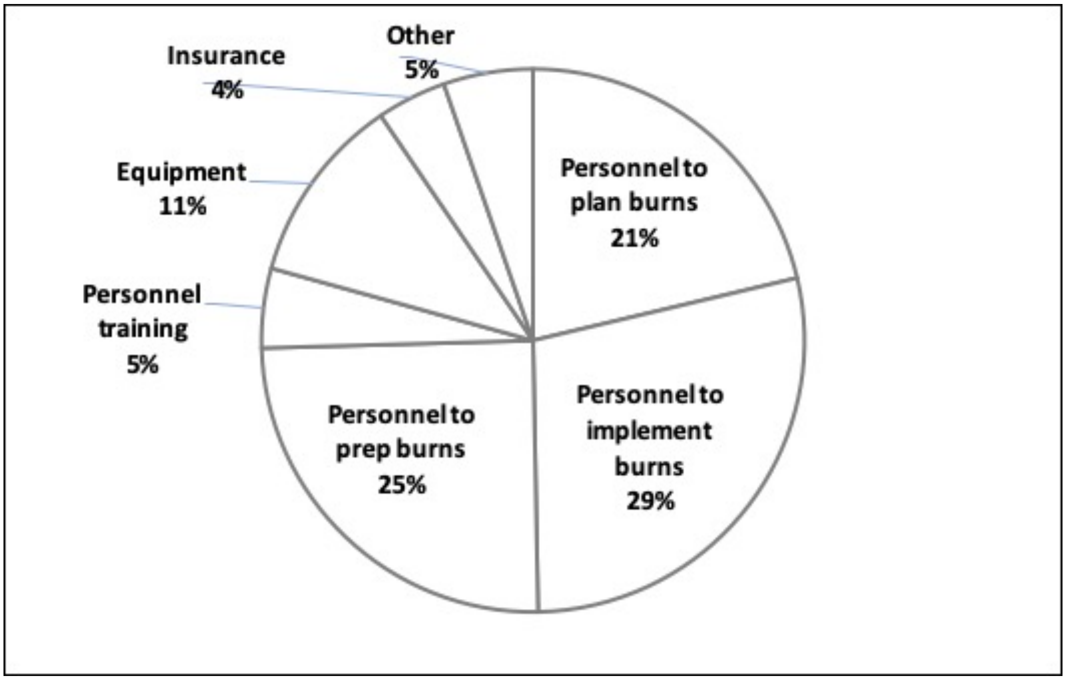

Figure 30. Top Three Budget Items to Increase Financial Resources Allocated to Prescribed Fire Expansion. Fire managers were asked to rank the top three budget items they would increase financial resources toward to expand prescribed burn area, and their responses were summed. Other items included National Environmental Policy Act specialists, public education, and specific equipment needs (e.g., vehicles).

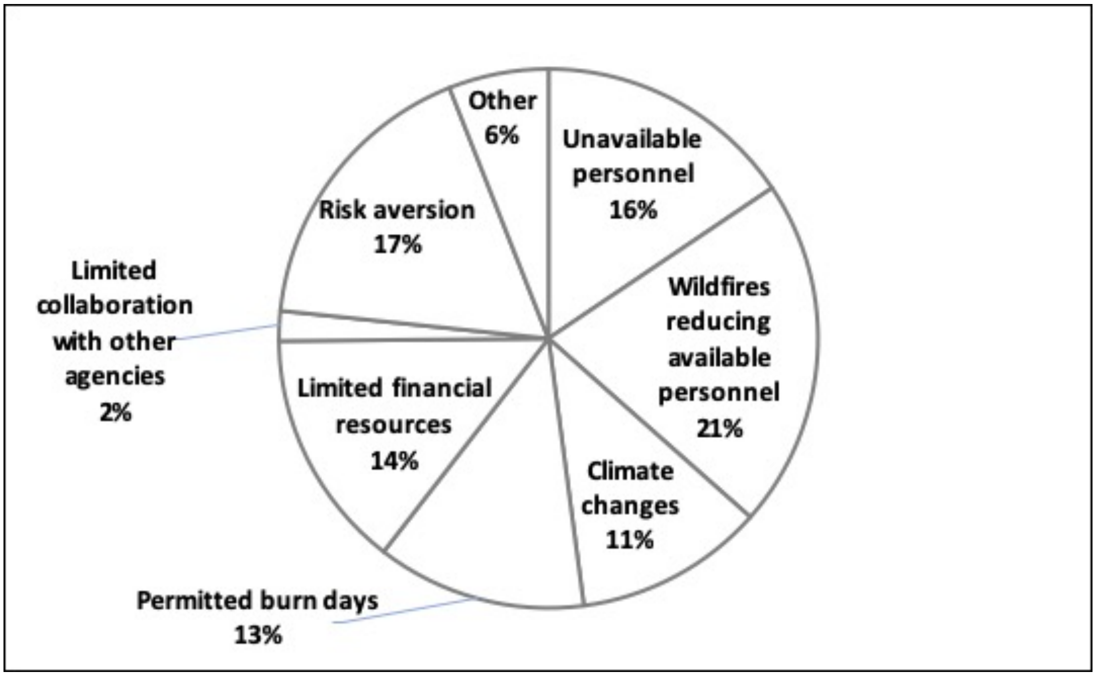

Figure 31. Top Three Burn Window Constraints. Fire managers were asked to rank the top three constraints to their agency's burn window, and their responses were summed. Other responses included National Environmental Policy Act procedures, ecological objectives and endangered species, limited available contractors and specialists, and air quality permits.

Table 9. Agency/Organization Participation in Collaborative Prescribed Fire Programs. Managers were asked if their agency or organization participated in these collaborative programs. 'Other' programs in this category included the California Deer Association (5%), and a variety of other local programs, such as the Sierra Nevada Conservancy, the USDA Natural Resource Conservation Service Environmental Quality Incentives Program, and local fire departments.

Collaborative Prescribed Fire Program	Agency Participation (%)
Prescribed Fire Training Exchanges (TREX)	64
CAL FIRE programs	63
California Fire Safe Council	41
Joint Chiefs Landscape Restoration Partnership	20
Tribal Forest Protection Act	9
California Department of Fish and Wildlife	7
Other	32

DISCUSSION

Interagency Collaborations

Interagency and inter-governmental collaboration to initiate prescribed burning have established systems of polycentric governance to address the pernicious issue of wildfire risk in northern California (Kelly et al. 2019; Crowder 2019). Diverse government agencies within State, Federal, and Tribal government are collaborating with NGOs to create a fire culture that embraces active anthropogenic ignitions, and leverages resources and capacities to expand prescribed burning. These diverse partnerships occur through two complementary efforts on private, Tribal, and public lands. The first initiative aims to train and hire professionals to implement and plan prescribed burns, and the second initiative serves to educate and empower property owners and community members to cooperatively support burning on privately owned parcels. The federal Joint Chiefs Partnership, the Collaborative Forest Landscape Restoration Program, CAL FIRE Forest Health Grant Program, and Fire Learning Network programs all demonstrate that with additional resources, prescribed burning can expand in both applied area and frequency (Butler and Goldstein 2010; Butler 2013; Spencer et al. 2015; Kelly et al. 2019; Schultz and Moseley 2019).

These findings concur with those from recent studies on the constraints to prescribed fire in northern California and the American West (Quinn-Davidson and Varner 2012; Schultz et al. 2018; Miller et al. 2020). In particular, agencies require sufficient and sustained funding to hire personnel to meet their prescribed fire objectives, while effective collaborations among federal land management agencies and air quality regulators have been successful at advancing prescribed fire objectives throughout the American West (Schultz et al. 2018; Miller et al. 2020). Coordination between the California Air Resources Board and federal agencies shows that establishing communication protocol can support prescribed burning, and facilitate flexible permitting (Ahuja and Proctor 2018). Additionally, the positive communication fostered between Fire Safe Councils and the North Coast Air Quality Management District also illustrates that relatively small local organizations with limited resources can streamline air quality permitting processes. These results also corroborate findings from Schultz et al. (2018) that the landscape of constraints and facilitators to prescribed burning is quite diverse, and successful implementation may depend on collaborative leadership from both residents and fire managers. Coordination between public land managers and NGOs through Fire Safe Councils has served to reduce public concerns toward prescribed burning. Investing in communication to WUI residents may serve to reduce their apprehension associated with prescribed fire and, in turn, minimize the politically-associated risk aversion of upper managers.

These forms of polycentric fire governance demonstrate the potential for effective collaboration across diverse entities, and serve to assist with efforts to revitalize prescribed fire knowledge. However, to expand prescribed burning and create fire-adaptive communities, major structural changes in political economy, land use, and legal frameworks still are required. Specifically, fire managers, and particularly Tribal members articulated the following constraints: 1) insufficient funding to enact prescribed fire plans; 2) inequities in the current distribution and control of land ownership; and, 3) entrenched centralized regulatory power of the state. A vision of Tribal sovereignty proposes to radically upend these three constraints to prescribed fire expansion. Tribal engagement in polycentric fire governance is the pathway Tribes perceive to be the most effective pathway to this vision, and yet, Tribal members recognize the limitations of such an approach, and feel ideally that the devolution of jurisdiction to Tribes would be the most successful and just.

Financial Resources

Because state and federal regulations govern prescribed burning on public and Tribal lands, land management agencies require additional personnel to implement policy objectives and expand prescribed burning under these regulations. In response to the destructive 2017 and 2018 wildfires coupled with advocacy by organizations like the Northern California Prescribed Fire Council, the State of California has been adopting new legislation to expand personnel for prescribed burning (Crowder 2019). As required by Senate Bill 901 (2018), the state increased appropriations for prescribed burning, and when compared with the 2017-2018 budget, the 2019-2020 State budget funded ten new prescribed fire crews with 157 new positions. They also initiated a new burn boss curriculum to standardize and increase certified burn bosses under the 2018 Senate Bill 1260 (California Legislative Analyst's Office 2019; Crowder 2019). Managers expect these changes will contribute to increased prescribed burning in certain regions of the state with a larger WUI. Yet, a similar increase in positions to conduct California Environmental Quality Act reviews for planned projects will be necessary to compliment this expansion in prescribed fire crews.

New sources of financial support for prescribed burning have also been created within local jurisdictions. For example, after repeated destructive wildfires in Sonoma County, residents voted with 74% approval to increase the sales tax to generate funds for fuel reduction in county parks in 2018. Residents were convinced of the value of prescribed burning and fuel reduction after years of defraying these costs produced disastrous air quality and home destruction in communities beyond the traditional WUI area. However, in 2020, a larger sales tax increase on the Sonoma county ballot for fire protection districts received only 64% of the vote, but required 66% approval to pass. Although this particular measure fell short of approval, six parcel taxes for local fire protection districts have passed in the county since 2018 (Rossmann 2020). These changes may be an indication that voters are willing to reverse decades of anti-tax policies that have defunded fire protection across California (Simon 2017).

On federal public lands, hiring additional fire management personnel remains a major constraint because the funding for these positions has been insufficient, and is determined by complex political appropriations (Pyne 2004; Hudson 2011). Congressional appropriations for Tribal self-governance and fire management programs have never been adequately funded, despite treaty and trust obligations (Wilkins and Stark 2017). Federal neoliberal policies embrace austerity measures in government budgets, environmental deregulation, and privatization of forest and fire management through contracting (Brick 1995; Hejny 2018). While the community fire planning processes and stewardship contracting in the HFRA can be construed as undermining NEPA and privatizing the Forest Service (Davis 2004), these processes have been used to effectively expand prescribed burning and restoration activities across public lands in northern California (Fleeger 2008; Jakes et al. 2011; Jakes and Sturtevant 2013). However, the scapegoating of NEPA and CEQA as prescribed fire inhibitors could be addressed by hiring and training additional specialists with expertise in fire ecology to conduct environmental reviews. For example, managers most frequently identified the limited availability of cultural resource specialists, and that additional personnel would accelerate NEPA/CEQA review. In the Klamath region, the Six Rivers National Forest contracts with the Karuk Tribe to conduct cultural resource reviews of proposed forest and prescribed fire activities under NEPA, developed by the Tribe and the WKRP. Such collaborations to conduct cultural resource reviews would also support consultation requirements and ensure Tribes are directly involved in forest and fire planning (Long et al. 2018b).

The Karuk Tribe and its partners in the WKRP have recently secured considerable financial support through stewardship contracting mechanisms, and other funding sources, to support their grassroots and collaborative projects. Many of the prescribed fires and fuel reduction measures on National Forests are now conducted by the Karuk Tribe's fire and natural resource management staff and the OSBFSC under the leadership of the Tribe (Vinyeta and Lynn 2015). The Tribe has used the decentralization of decision-making in the Forest Service to increase their capacity and autonomy over fire management. The Karuk Tribe has learned from the problematic Orleans Community Fuel Reduction project experience (Scott-Goforth 2013), and has established their own expertise to avoid the consequences of Forest Service contracts with timber companies and non-Tribal organizations. Decentralization and devolution can support fire and ecological restoration objectives, but relying on timber extraction revenues for funding often may conflict with fire and restoration efforts.

In instances like the Orleans Community Fuel Reduction project, collaborative management may be perfunctory for federal and state agencies, and entangle Tribal members in costly bureaucratic processes with few obvious accomplishments (Nadasdy 2005). Yet, the Karuk and Yurok Tribes have developed ways to expand their decision-making power, and assert their legitimacy as well as their ability to implement their plans. Nonetheless, Tribes remain beholden to the budget constraints of the Forest Service, CAL FIRE, and other state agencies to achieve their goals. In the short-term, subsets of funds from these agencies can support the legal and regulated burning programs of Tribes, but reliance on external funds that fluctuate with the politics of Washington DC and Sacramento is unsustainable. To create alternative funding streams, the Karuk Tribe recently established an eco-cultural revitalization fund to raise financial resources through private foundations and donors, and the Yurok Tribe has entered the carbon sequestration market to generate long-term funding for its forest and fire restoration program (Manning and Reed 2019). Although this market mechanism remains controversial (Blanchard and Vira 2017), the US Congress has limited Tribal funding, leaving Tribes with few viable alternative funding streams.

Centralized Fire Governance

Across northern California, fire managers are hampered by the centralized decision-making processes surrounding the permitting of prescribed burning. Specifically, the banning of prescribed burning across the state by Forest Service regional staff and CAL FIRE upper management during wildfires or severe fire weather prevents implementation when the bans coincide with optimal prescribed fire conditions in other regions. Even without a statewide burn ban, wildland fire teams are prioritized for wildfire suppression, and often sent to other regions, or prevented from conducting prescribed burns so that they are available for a potential wildfire. This situation exemplifies the wildfire paradox in action, where a positive feedback loop exists for reactive suppression activity resulting in limited resources for proactive preventative measures (Calkin et al. 2015; Ingalsbee 2017). Yet, little available evidence exists to support having supplementary personnel on wildfires during extreme fire weather to achieve containment—instead wildfire containment is likely driven primarily by changes in extreme weather conditions

(Finney et al. 2009). Yet, the Forest Service budget structure incentivizes wildfire suppression over prescribed burning. For example, if a wildland fire team is sent to a wildfire elsewhere, their costs are paid through a different suppression fund, defraying any costs to their home unit (e.g., a national forest or Tribe). Thus, current budgetary incentives favor sending personnel to wildfires instead of maintaining their availability for prescribed burning within their home unit (Donovan and Brown 2007; North et al. 2015).

Expanding prescribed burning requires major changes to wildfire management in order to reduce suppression costs (Dunn et al. 2017; Ingalsbee 2017). Allowing wildfires to burn as ‘managed wildfires’ is an acceptable management decision on Forest Service lands, and is less costly than current suppression tactics (Donovan and Brown 2007; Houtman et al. 2013; North et al. 2015). However, CAL FIRE does not have a similar policy, which may cause conflict between agencies when fires burn in different jurisdictions (Firefighters United for Safety Ethics and Ecology 2019; Miller et al. 2020). Extending a polycentric fire governance model to these incompatible policies may allow for progress in managing wildfire (Kelly et al. 2019). Furthermore, both decentralizing permissible burn day decisions to reflect local ecological and climate realities and providing regions with greater autonomy over their personnel would facilitate prescribed burn objectives.

Decentralized Fire Governance

To decrease the costs of prescribed burning that are primarily associated with paying professionals, or individual landowners’ time and money limitations (Fischer 2011), the Northern California Prescribed Fire Council, the Fire Learning Network, Tribal members, and others have supported decentralized prescribed burn associations (PBAs) and the Indigenous Peoples Burning Network (IBPN) that bring trained property owners and volunteers together to conduct burns on privately-owned land (Toledo et al. 2014; Weir et al. 2016; Crowder 2019). These associations and networks capitalize upon the neoliberal support of decentralization in forest governance (McCarthy 2005), and yet, do not aim to reproduce capitalist social relations of individualism or commodification. Rather, they are rooted in concepts of mutual aid, and the non-capitalist vision of Indigenous autonomy (Alfred 2005) that can support the revitalization of relatively small-scale fire-based subsistence (Hillman and Salter 1997; Robbins et al. 2016; Sarna-Wojcicki et al. 2019).

Many of the leaders of these organizations have developed relationships of trust with regulators and managers through their professional roles. These relationships assist them in circumventing regulatory concerns and accessing equipment to support burns (Weir et al. 2016).

This social capital built into the structure of PBAs extends a social insurance to allay liability concerns, which is necessary given the difficulty and expense associated with purchasing insurance on the market. These relationships also expand social networks of landowners and burners, and serve to enhance trust among community members and facilitate the expansion of a positive prescribed fire culture (Toledo et al. 2014). These associations have also organized to change fee structures for burn permits, and thus, have been effective political forces to change local regulatory structures (Crowder 2019).

The grassroots IPBN effort to collaboratively burn, however, highlights the challenges of expanding prescribed burning under the existing property ownership regime, where the majority of Tribal ancestral territory remains under the jurisdiction of the Forest Service, Park Service and private timber companies (Huntsinger and Diekmann 2010; Norgaard 2019). Extensive California Indian land dispossession substantially limits the efficacy of this decentralized burning network, as many families no longer own properties, or their properties are highly fragmented, and thus, challenging, at best, to manage (Shoemaker 2003; Carroll et al. 2010). As Agrawal & Ostrom (2001) emphasize, if governments permit decentralized decision-making, but do not also devolve property use or access rights to Indigenous and local communities, then efforts to reform management efforts will unlikely be effective. Through the WKRP, the Forest Service is progressing toward reinstating Tribal management of certain circumscribed areas (Vinyeta and Lynn 2015; USDA Forest Service PSW Region 2018), while the Yurok Tribe has been purchasing land and advocating to legislatively transfer Forest Service property to reservation lands (Manning and Reed 2019; Mukherjee 2019). However, under the control of Tribal governments, cultural burning on Tribal land may still be inhibited by highly regulated and under-resourced Tribal institutions (Alfred 2005; Carroll 2015; Nadasdy 2017). Efforts to co-manage and re-patriate lands are promising, but they do not necessarily support familial control over lands, which is historically how Karuk and Yurok Tribal members managed fire and resources (Waterman 1920; Bettinger 2015; Norgaard 2019). Therefore, a regional effort to return privately-owned lands to dispossessed Tribal members also has potential to expand prescribed burning and address social injustices (Kelly et al. 2013; Hurwitz and Bourque 2018).

To expand prescribed burning, polycentric and intercultural fire governance is also ascendant in South America and Australia where Indigenous burning and fire knowledge are being recognized by state agencies as critical components of fire regimes and to mitigate wildfire spread (Russell-Smith and Cook 2013; Mistry et al. 2019). Similar to CAL FIRE Forest Health grants in California, Indigenous fire management programs in northern Australian savannas have also been funded through carbon sequestration markets (Russell-Smith and Cook 2013; Fache and

Moizo 2015; Petty et al. 2015). However, Aboriginal communities have been critical of these programs because they are tied to external metrics associated with carbon offsets, and thus, the intent of burning has emphasized achieving carbon emission reductions as opposed to the nuanced ecocultural burning objectives associated with Indigenous livelihood and culture (Fache and Moizo 2015; Petty et al. 2015; Mistry et al. 2019). In Australian and South American contexts where fire governance is comparatively decentralized and Tribal sovereignty and land title is less encumbered by colonialism, Indigenous prescribed burning is achieving desired social and ecological outcomes without a heavy reliance on external funding and metrics (Codding et al. 2016; Welch and Coimbra Jr 2019).

Where governments and communities acknowledge the benefits of prescribed fire, diverse modes and innovative mechanisms of implementation have emerged such as professional prescribed fire crews, Indigenous fire ranger programs, and prescribed burn associations (Kobziar et al. 2009; Toledo et al. 2014; Fache and Moizo 2015; Petty et al. 2015; Weir et al. 2016; Crowder 2019). Yet, despite favorable Federal and California state governmental rhetoric toward prescribed fire, centralized government funding and associated programs have been insufficient for sustaining proactive prescribed fire programs in northern California (Quinn-Davidson and Varner 2012; Kolden 2019; Miller et al. 2020). Furthermore, these centralized bureaucracies often lack the local fire knowledge that has co-evolved with fire ecologies, and thus, have the potential to impose burning prescriptions that are not compatible with diverse social or ecological needs; an emphasis on prescribed burning for hazardous fuel reduction, for example, may not have the same effect as burning for culturally-important species or eco-cultural restoration (Eriksen and Hankins 2014; Lake et al. 2017). Therefore, governments and institutions can adjust regulations to devolve decision-making to local communities, especially those that have autochthonously established rules, norms, and infrastructure for burning. Given their deep temporal and place-based ties that have motivated the rehabilitation of human-fire relationships integral to their culture, Indigenous communities, such as the Karuk and Yurok, are particularly well positioned to determine the application of prescribed fire in their territories.

APPENDIX

A. Prescribed Fire in Northern California Survey Instrument

Q1 What is your email address?

____

Q2 What type of entity do you primarily work for with regard to prescribed fire?

- ○ US Forest Service
- ○ Bureau of Land Management
- ○ American Indian Tribe
- ○ CAL FIRE
- ○ National Park Service
- ○ California State Parks
- ○ Non-governmental organization
- ○ Private company
- ○ Other (please specify) ____

Q3 Which park, forest district, field office, or unit do you work for to conduct/plan prescribed burns?

____

Q4 What is your position?

____

Q5 Within your position, how do you support prescribed burning?

____

Q6 What were your agency/organization’s annual prescribed burn area targets in 2018 (if known)?

- ◯ 0 - 25 acres
- ◯ 26 - 100 acres
- ◯ 101 - 500 acres
- ◯ 501 - 999 acres
- ◯ 1000 + acres

Q7 How many total acres did your agency/organization burn in 2018?

- ◯ 0 - 25 acres
- ◯ 26 - 100 acres
- ◯ 101 - 500 acres
- ◯ 501 - 999 acres
- ◯ 1000 + acres

Q8 Since 2013, has your agency/organization made progress toward increasing the overall area of prescribed burns?

- ◯ Yes
- ◯ No

Q9 Please estimate how many more acres your agency/organization burns annually compared to 2013:

- ◯ 1 - 10 acres
- ◯ 11 - 51 acres
- ◯ 51 - 100 acres
- ◯ Other (please specify) ____

Q10 Since 2013, what were the most important actions your agency/organization took to increase prescribed burning (1 being most important)?

- ◯ 1 ____
- ◯ 2 ____
- ◯ 3 ____

Q11 Of the following prescribed burn objectives, which does your agency/organization regularly accomplish, and which are more difficult to accomplish?

	Regularly Accomplish	Difficult to accomplish	N/A
Fuel reduction	◯	◯	◯
Enhancement of Nontimber (special) forest products	◯	◯	◯
Enhancement of ecocultural resources (e.g. acorns, basketry materials)	◯	◯	◯
Forage enhancement for deer/elk/livestock	◯	◯	◯
Ecological restoration	◯	◯	◯
Other (if applicable, please specify)	◯	◯	◯

Q12 Have interagency and community-based collaborations supported prescribed burning efforts within your agency/organization?

- ○ A great deal
- ○ A lot
- ○ A moderate amount
- ○ A little
- ○ N/A

Q13 How have these collaborations specifically supported prescribed burning?

Select all that apply

- ☐ Provided funding
- ☐ Provided personnel and equipment
- ☐ Provided training
- ☐ Supported with burn planning and permitting
- ☐ Supported with community outreach
- ☐ Other (please specify) ____

Q14 Has your agency/organization participated in collaborative burning supported by any of the following programs?
Select all that apply

- ☐ Prescribed Fire Training Exchanges (TREX)
- ☐ Joint Chiefs Landscape Restoration Partnership
- ☐ CAL FIRE funds or programs (e.g., Vegetation Management Program, Forest Health grants)
- ☐ California Department of Fish and Wildlife funds
- ☐ California Fire Safe Council funds
- ☐ Tribal Forest Protection Act
- ☐ Other (Please specify) ____
- ☐ N/A

Q15 How many times has your agency/organization participated in prescribed fire training exchanges (TREX)?

- ○ 1 - 2 times
- ○ 3 - 4 times
- ○ 5 - 6 times
- ○ 7 + times

Q16 Was TREX useful for your agency/organization?

- ○ Very useful
- ○ Moderately useful
- ○ Slightly useful
- ○ Not useful

Q17 What are the specific benefits of TREX for your agency/organization?

____

Q18 If your agency/organization had unlimited financial resources, which of the following would be your top three impediments to prescribed burning? **(Drag items and drop in the box)**

Top three impediments without financial constraints
______ Coordination of multiple property owners
______ Air quality permitting
______ NEPA/CEQA processes
______ Permissive legal burn days
______ Public concerns
______ Wildfires reducing available personnel
______ Short burn windows
______ Other (please specify)

Q19 If your agency/organization could allocate more financial resources to expand annual prescribed burn area, which would be the top three budget items you would increase? **(Drag items and drop in the box)**

Top three items to increase financial resources

______ Personnel to plan burns

______ Personnel to implement burns

______ Personnel to prep burn units

______ Personnel training

______ Equipment (e.g., engines, hose, etc.)

______ Insurance policies

______ Other (please specify)

Q20 Which of the following do you believe constrains your agency/organization's burn window? Please rank the pertinent choices, with the first item being the greatest contributor.

Greatest constraints to burn window

______ Unavailable personnel

______ Wildfires reducing available personnel

______ Climate changes (e.g., drought, unpredictable precipitation)

______ Permissive burn days

______ Limited financial resources

______ Limited collaborative management with other agencies

______ Risk aversion

______ Other (please specify)

Q21 Do you believe the legal burn window (permissive burn days) has become shorter since 2013?

- ○ Yes
- ○ Maybe
- ○ No

Q22 How often do the following landscape features discourage your agency/organization from planning prescribed burns nearby?

	Most of the time	Occasionally	Rarely	Never
Private properties and structures	○	○	○	○
Cultural resources	○	○	○	○
Endangered species	○	○	○	○
High fuel load areas	○	○	○	○
Recreation attractions	○	○	○	○
Other (please specify)	○	○	○	○

Q23 Does your agency/organization have sufficient resources to reduce fuel loads to prepare sites for prescribed fire?

○ Always

○ Most of the time

○ Occasionally

○ Rarely

○ Never

Q24 Please explain how the Endangered Species Act has caused your agency/organization to limit prescribed burning plans:

____

Q25 Do planning procedures like CEQA or NEPA impede your agency/organization's ability to implement and increase prescribed burns?

- ○ Always
- ○ Most of the time
- ○ Occasionally
- ○ Rarely
- ○ Never
- ○ N/A

Q26 Does your agency/organization have sufficient specialists available to efficiently conduct CEQA and NEPA assessments of proposed prescribed burns?

- ○ Always
- ○ Most of the time
- ○ Occasionally
- ○ Rarely
- ○ Never
- ○ N/A

Q27 If your agency/organization could add staff to streamline the completion of CEQA or NEPA requirements for prescribed burning, which would be the top three positions? **(Drag items and drop in the box)**

Top 3 Staffing Positions to Streamline CEQA/NEPA
______ Cultural Resource Specialist
______ Wildlife biologist
______ Forester
______ Botanist
______ Environmental Planner
______ Other (please specify)

Q28 Is your agency/organization limited by the availability of burn bosses to conduct prescribed burns?

- ○ Always
- ○ Most of the time
- ○ Occasionally
- ○ Rarely
- ○ Never

Q29 Has the lack of available wildland fire crews or modules limited your agency/organization 's ability to conduct prescribed burns?

- ○ Always
- ○ Most of the time
- ○ Occasionally
- ○ Rarely
- ○ Never

Q30 If your agency/organization could increase personnel to expand prescribed burning capacity, which type of personnel would be most beneficial? (Please rank, 1 being the greatest, 5 being the least)

_______ Burn bosses
_______ Fire managers
_______ Wildland fire crews/modules
_______ Scientists/Specialists
_______ Cultural Resource Technicians

Q31 Since 2013 has your agency/organization been able to make improvements to the following prescribed fire impediments?

	Improved	Unchanged	Declined
Air quality permitting	○	○	○
NEPA/CEQA assessments	○	○	○
Personnel resources	○	○	○
Public concerns	○	○	○
Financial resources	○	○	○
Fuel loading	○	○	○
Property owner coordination	○	○	○

Q32 What specific actions has your agency/organization taken to overcome or reduce the following impediments to prescribed burning?

- ◯ Air quality permitting ____
- ◯ NEPA/CEQA assessments ____________________________________
- ◯ Personnel resources ____
- ◯ Public concerns ____
- ◯ Financial resources ____
- ◯ Fuel loading ____
- ◯ Property owner coordination ___________________________________
- ◯ Other (please specify) ____

Q33 Has your agency/organization attempted to reduce impediments with limited effectiveness?

- ◯ Yes
- ◯ No
- ◯ N/A

Q34 What were those efforts and why weren't they effective?

____

Q35 Are there changes to specific laws and policies that you believe would support the expansion of prescribed burning?

____

Q36 Are there any promising developments that you believe will aid in expanding prescribed burning in the next decade?

____

Q37 Thank you for participating in this survey!

Do you have anything else you would like to add?

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